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NAVY SCIENTIFIC PAPERS, No. 7.

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LECTURE

ON THE

TURNING POWERS OF SHIPS.

BY

W. H. WHITE,
ASSISTANT CONSTRUCTOR, R. N.

FROM THE JOURNAL OF THE ROYAL UNITED SERVICE INSTITUTION.

BUREAU OF NAVIGATION,
NAVY DEPARTMENT.

WASHINGTON:
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Washington, D.C.

ON THE TURNING POWERS OF SHIPS.

By W. H. White, *Assistant Constructor.*

In acceding to the request of the council, and preparing a paper on "The Turning Powers of Ships," it seemed advisable to consider those parts of the subject which have the greatest practical interest for naval officers, as affecting the management of existing ships of war. In these vessels the rudder is the chief source of maneuvering power, aided in many cases by the action of the propellers; and to these means of turning I shall chiefly refer. Of the various plans which have been proposed or tried for increasing the maneuvering capabilities of ships I shall say but little; of the mechanical appliances by which the movements of the helm are controlled I shall attempt no description. My principal aim will be to summarize and illustrate, in as brief and practical a manner as possible, the principles which govern the behavior of screw steamships when turning under the action of their rudders or propellers.

The general theory of the action of the rudder was clearly stated in the earliest treatises on naval architecture published during the eighteenth century. Our present knowledge of the subject owes its chief extensions not to mathematical investigation, but to direct experiment. It is customary both in the Royal Navy and in foreign navies to make a series of turning trials in connection with the steam trials of a new ship before she proceeds to sea. These preliminary or "constructors'" trials are useful not only as affording thorough tests of the efficiency of the rudder and steering gear in a new ship; they have also furnished valuable data as to the steering qualities of ships of different classes, and have helped to correct some deductions made from purely theoretical investigations. As usually conducted, these constructors' turning trials are made in smooth water and light winds, with the helm hard over to port or to starboard, the ship running with engines at full or half power. The observations made include (1) a record of the time occupied in putting the helm over; (2) a record of the time occupied in turning the half circle and full circle, respectively; (3) a measurement of the diameters of the "circles" in which the ship turns. In some cases the turning trials are extended to other speeds than those corresponding to full or half power; or to angles of helm varying from "hard over" down to small angles with the keel line; but these extensions are not common. Additional trials are also made in twin-screw ships, or ships with other kinds of duplicate propellers, to determine their behavior when one propeller is working ahead and the other astern, or when one propeller only is at work. It need hardly be added, however, that even the fullest constructors' trials do not furnish all or nearly all the information respecting the steering qualities of ships which commanding officers require. Continued experience in management, and the further trials which can be made during the service of a ship at sea, enable commanding officers to acquire an intimate knowledge of the turning powers of their ships under various conditions of wind, sea, speed, and helm-angle. The experience thus gained is of the greatest value, not merely as regards the management of individual ships, but in the aggregate it should form the basis of any system of naval tactics. In the Royal Navy, the regulations provide for the conduct of such turning trials in all new ships, and for the record of the results in the "Ship's Books," for the information of officers who may succeed to the command. In the French navy also great attention is bestowed upon similar trials of ships attached to the experimental squadrons; and a very excellent account of the method pursued will be found in Captain (now Admiral) Bourgois' "*Méthodes de Navigation et d'Expériences,*" published about twelve years ago.*

The conduct of these steering trials lies, of course, strictly within the province of the naval officer; but as a naval architect who has given much attention to the subject I may be permitted to indicate a few of the principal points upon which further information seems to be needed. And in order to do this as briefly as possible, I will first endeavor to sketch the circumstances attending the turning of a steamship, which is moving ahead on a straight course and with uniform speed, when the helm is put down.

It is worth notice that when a ship is moving ahead under the assumed conditions in smooth water and a dead calm, she is in *unstable equilibrium* so far as the maintenance of the straight course is concerned. That is to say, the action of a very small disturbing force will suffice to deflect her from that course. Directly the helm is put over, and an unbalanced pressure is developed on the rudder, that pressure constitutes a disturbing force, and the vessel begins to turn. Her angular motion is gradually accelerated as the helm angle is increased, and after the helm is "hard over." After reaching its maximum rate the angular motion of the vessel becomes uniform; and thenceforward if the helm-angle and revolutions of the engines remain unaltered the vessel continues to swing round through equal angles in equal times, her center of gravity describing a circular path, and all other points moving in concentric circles. When there is powerful mechanical steering gear, capable of putting rudders of large area over to good angles in very small times, this condition of uniform angular motion is quickly reached, probably by the time the head of the ship has swung through 360° or even a less angle from the original course. With manual power at the helm, it is stated on good authority that similar uniformity of angular motion is not obtained until the ship has completed two circuits or even more. The longer time occupied in putting the helm over with manual power accounts for this difference.

In order to determine the motion of the ship in turning, it is convenient to take the following:

(1.) The original straight course, as *line of reference*, from which to measure the angles turned through by the keel line of the ship in specified times.

(2.) The position of the center of the ship on the straight course at the instant when the helm begins to move over, as an *origin of co-ordinates*.

(3.) The path which the center of gravity describes while the ship turns, as that to be determined by observation. This will practically agree with the middle of the length in most ships.

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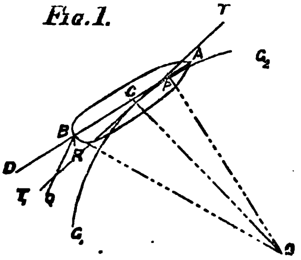
*Arthus-Betrand, editeur, Paris.

It will be obvious that if by observation we can determine the place of the center of gravity at any instant with respect to the original course and the selected origin of co-ordinates, the path can be constructed. Also, that if the angles through which the head of the ship has turned are noted at the same times as the positions of the center of gravity are observed, the instantaneous positions of the keel line are found, and the instantaneous inclinations of the keel line to the corresponding tangents to the path of the center of gravity can be ascertained.

When the motion of rotation has become uniform, and the center of gravity is moving in a circle, the keel line of the ship makes a *constant angle* with the tangent to the circular path of the center of gravity. Fig. 1 illustrates this case. A represents the bow, and B the stern of a ship. G shows the position of the center of gravity on the keel line AB. O is the center of the circular paths in which G, A, and B are moving. TGT_1 is the tangent to the path (G, G_1, G_2) of the center of gravity; and the angle (AGT) made by the keel-line with the tangent is termed by the French *angle de dérive*, or "drift angle." The value of this drift angle varies considerably in different vessels, and in the same vessel under different conditions of speed and helm-angle. In the Thunderer, for example, with a constant helm angle, but with variations in the speed, the following results were obtained:

Fig. 1.



Speed on straight.	Drift angle.	Diameters of circles (feet).	
		Bow.	Stern.
Knots.	°		
8.2	5¾	1,350	1,410
9.4	8¾	1,255	1,345
10.4	9¼	1,240	1,340
11.14	9½	1,240	1,340

Other cases are on record where the drift angle has been 16° or 18°. No general law has yet been formulated for the magnitude of the drift angle, but it is generally agreed that it increases (*a*) with increase in speed, when helm angle and rudder area are constant; (*b*) also with increase in rudder area and helm angle, speed being constant. As a consequence of the drift angle, the bow and stern of the ship revolve in circles of different diameters, and in the above table the results for the Thunderer furnish an illustration of the fact. Furthermore, in any given time the head of the ship must have turned through an angle from the original course which exceeds the angle turned through by the center of gravity by a quantity equal to the drift angle.

Turning again to Fig. 1, let P be the foot of a perpendicular let fall from the center O upon the middle line of the ship (AB). Then to an observer on board the ship, P will appear to be the "pivot point" about which the angular motion of the ship is being performed at each instant; for it will be seen that the keel line AB coincides with the tangent to the path of the point P, which is not true of any other point on the keel-line. In other words, at P there is no drift angle; whereas for every other point in the keel line there is a drift angle, the value of which is easily determined when that for the center of gravity, G, and the radius, OG, have been determined. In the case of the Thunderer, the pivot point, P, varied from 67 to 103 feet before the center of gravity, or from about 80 to 40 feet from the stern. As the speed and drift angle increased, so the pivot point moved forward. It need hardly be added that the point O is the true center of the motion of the ship in turning, although P appears to an observer on board to be the pivot on which the ship turns during the time she has uniform angular velocity.

Another circumstance requiring notice in connection with the uniform turning motion now under consideration is the *loss of speed* sustained by the ship when turning, as compared with her speed on the straight course from which she began to turn. Taking several cases where this loss has been carefully measured, I find that the speed of advance on the circular path has only been *seven-tenths* or *eight-tenths* of the speed on the straight. It is often supposed that this loss of speed is chiefly due to the "drag" of the rudder. Any one who investigates the matter will become convinced that the rudder pressure has little to do with this considerable decrease in speed; the real cause is to be found in the drift angle. Glancing once more at Fig. 1, it will be evident that, at each instant, while the propelling force is delivered along or parallel to the keel line, the actual motion of the vessel in turning is not directly ahead, but sideways. In fact, the motion bears a considerable resemblance to the motion of a ship sailing on a wind; and there is a considerable pressure developed on the side of the bow most distant from the center O. This pressure not merely checks the speed of the ship, but exercises a considerable turning effect, assisting the pressure on the rudder. The importance of this assistance will appear more clearly when it is considered that owing to the rotary motion of the vessel while turning, the flow of water at the stern is different, even in screw steamers, from that which would take place before the angular motion became considerable. In fact, the *effective* helm angle becomes considerably reduced from the angle RBD, Fig. 1, which the rudder makes with the keel line AB, produced. So far as I am aware, we have no exact data for estimating the amount of this reduction; but French experimentalists assert that it approaches to equality with the drift angle for the rudder axis B. If OB is joined, and BQ drawn perpendicular to it, then the effective helm angle, according to the French rule, should be taken as approximately equal to RBQ, and not to DBR, or a reduction of at least *one-half* from the angle made with the keel-line, even in single-screw ships. Approximately the pressure on the rudder may be expressed as a function of the speed of the ship, and the *sine* of the effective angle of helm; so that the loss of rudder pressure consequent upon such a reduction in the effective angle as is asserted to take place will be very considerable. Apart from exact measures of the reduction, there can be no question as to the fact; and it is one of the matters upon which further experiments might well be made in English ships. With the assistance of a dynamometer to register the strains on the tiller end when the helm is first put over, and after the turning motion has become uniform, it would be an easy matter to discover the variations in the effective helm angle if the revolutions of the engines and speed of the ship were also observed.

In concluding these remarks on uniform angular motion, it may be well to refer to the *heeling* which accompanies turning. The forces which tend to produce heeling are as follows:

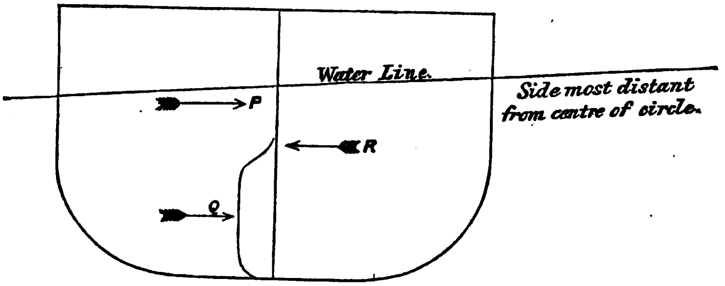
1. The centrifugal force acting outwards through the center of gravity of the ship, and tending to make her heel away from the center of the circle.

2. The lateral component of the rudder pressure, acting through the center of pressure of the rudder at some depth below the center of gravity of the ship, and tending to make her heel inwards towards the center of the circle.

3. The lateral component of the fluid resistance on the outer side of the ship, which equals in magnitude the resultant of the centrifugal force and the rudder pressure, and acts through the center of lateral resistance.

Fig. 2 shows the distribution of these forces in the Thunderer, determined from the turning trials made at Portland. Here again it is common to find the rudder pressure credited with the heeling effect; whereas it may, in most cases, be neglected in comparison with the centrifugal force. A fair approximation to the angle of heel for a ship in turning is given by the following equation:

Fig. 2.



$$\sin\theta = \frac{1}{32} \times \frac{d}{m} \times \frac{v^2}{R},$$

where θ = angle of heel,
v = speed of ship in feet per second,
R = radius of circle turned (in feet),
m = "metacentric height"—height of transverse metacentric above center of gravity,
d = distance of center of gravity above center of lateral resistance.

In the Thunderer, the center of lateral resistance was found to be from .43 to .49 of the mean draught below the water line; probably a fair approximation for war ships of ordinary form would be from .45 to .5 of the mean draught. From the foregoing equation it will be seen that—

The angle of heel varies (1) Directly as the *square of the speed* of ship;
(2) Inversely with the *metacentric height*;
(3) Inversely with the *radius* of the circle.

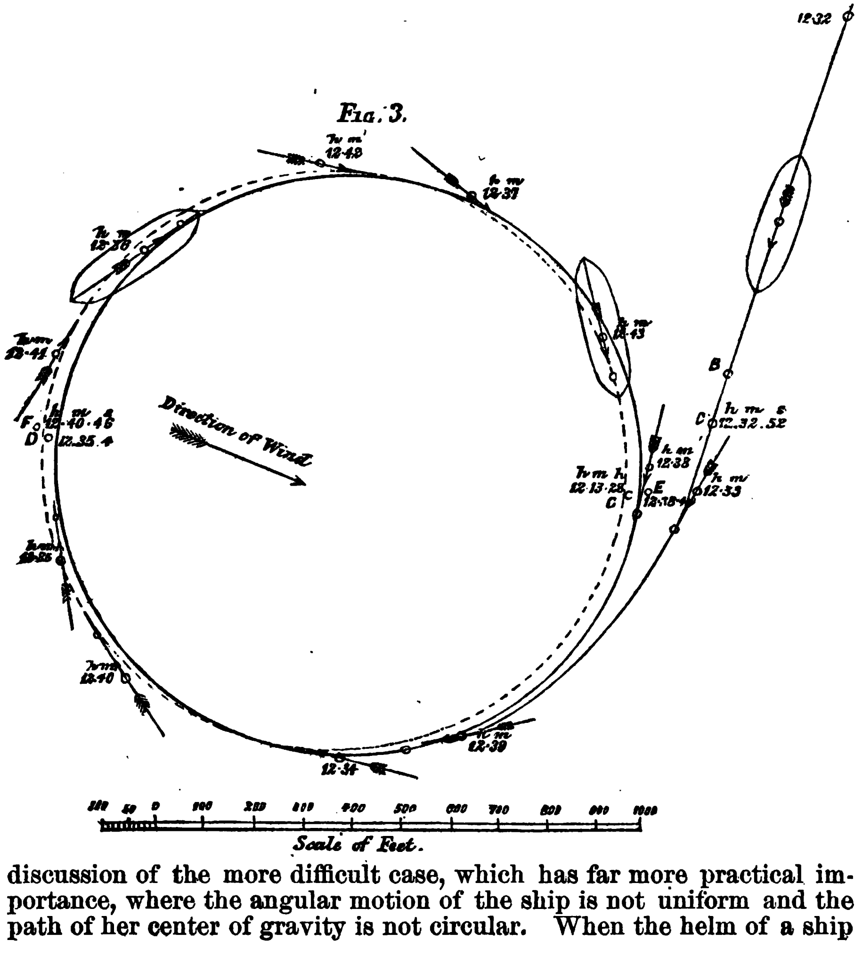
Hence it is obvious that ships of high speed, fitted with steam steering gear, capable of turning on circles of comparatively small diameter, are those in which heeling may be expected to be greatest. Moderate values of the metacentric height further tend to increase the heeling. If the speed be *doubled*, the angle of heel will be about *quadrupled*, if the radius of the circle turned and the metacentric height remain constant. In order to maintain a certain angle of heel under these altered conditions of speed, the metacentric height would also have to be quad rupled; but such an increase in stiffness is clearly undesirable even if it were practicable. The following figures may be interesting:

	Speed on straight.	Diameter of circle.	Draught.	Metacentric height.	Angle of heel.
	Knots.	*Feet.*	*Ft. in.*	*Feet.*	° ′
Thunderer	8.2	1,340	26 3	3.12	0 52
	9.4	1,250	26 1		1 11
	10.4	1,240	26 1		1 14
Tourville (French)	15	2,030	....	....	3 30
Victorieuse (French)	10	1,290	....	....	2 0

It is important to notice that in taking observations of the angle of heel for a ship in turning, allowance must be made for the effect of the centrifugal force upon the indications of pendulums or clinometers. The error of indication is always in excess, and the correction is very easily made when the diameter of the circle and time of turning have been ascertained.

In treating at some length the case of a ship turning uniformly in a circular path, I have endeavored to clear the ground somewhat for the discussion of the more difficult case, which has far more practical importance, where the angular motion of the ship is not uniform and the path of her center of gravity is not circular. When the helm of a ship

FIG. 3.



is put down, and she begins to turn away from a straight course, it is interesting to know (1) whether she will readily answer her helm; (2) what will be the path traversed by her center of gravity; (3) what will be the rate of growth of her drift angle; (4) what will be her gradual loss of speed as compared with her speed on the straight course. Probably the most important pieces of information in relation to naval tactics will be as follows: 1. The place of the center of gravity of the ship when her head has swung through 90° from her original course; that place being fixed (in the manner previously described) with reference to the original course and the position of the center of gravity thereon at the instant the helm begins to move over. 2. The speed of the ship when she has turned through the first 90°. 3. The time occupied in turning 90°. 4. The time and space required to reverse the course, turning through 180°.

It is singular to find on inquiry how meager is the information recorded on the first three of these points. I can discover no case except that of the Thunderer in which the actual path traversed by the center of gravity of the ship has been determined from the instant the helm was put down to the time when the turning motion had become uniform. All the facts as to these trials have been published in the report of the Inflexible committee, and they deserve the careful study of all naval officers. I do not propose to reproduce them here, but to use a few of the results only for purposes of illustration. Fig. 3 shows the course traversed by that ship, when turning from a straight path on which her speed had been 10.44 knots. On analyzing the companion diagrams for this speed, I find the following results, reckoning times from the instant when the helm was begun to be put over:

	Time.	At end of time.	
		Speed of ship.	Angular velocity per second.
	Seconds.	*Knots.*	° ′
To put helm over 31°	19	10.4	0 20
To turn ship's head 45°	56	9.25	1 18
To turn ship's head 90°	89	8.3	1 18
To turn ship's head 135°	123	7.75	1 15
To turn ship's head 180°	159	7.5	1 12
To turn ship's head 360°	320	7.14	1 6¾

At 360° the turning motion had become practically uniform. The conditions here traced for the Thunderer are representative for all steamships when turning under the action of their rudders from a straight course on which they were originally moving ahead. There will, of course, be differences in different ships as regards the times occupied in putting the helm down, or in passing through the various changes which precede the attainment of uniform angular velocity, as well as in the value of that velocity. But in all cases as a ship turns from her straight course she will be subjected to angular acceleration, her drift angle will gradually increase, she will heel more and more, and her speed will decrease. But by degrees these transitory conditions will pass away, if the helm is kept at a constant angle, and the engines at a nearly constant speed, and ultimately a state of uniform motion and steady heel will be reached such as I have previously attempted to describe.

Purely theoretical investigation does not enable one to lay down the path of the center of gravity of a ship from her straight course to the position occupied when the head has turned through 90°; nor are we much better off for the remaining part of her path until the turning becomes uniform. The greatest difficulty in framing the equations of motion arises from the uncertain state of our knowledge respecting the resistance offered by the water to the motion of the ship in turning. Hence it becomes necessary that the problem should be attacked by actual experiment, and careful observations made, which would enable the path traversed to be subsequently plotted. French writers assert that the curve traversed by a ship from the place where her helm is put over to her place when she has turned through 180°, can be treated without serious error as a circle touching the original course. The perpendicular distance from the place of the center of gravity when the head has turned through 180°, to the original course, is termed by the French the "diameter of evolution." Captain Colomb has proposed to call it the "tactical diameter." Unfortunately the Thunderer experiment shows that the French assumption as to the character of the curve is only a rough approximation; and apart from those experiments it is obvious that for different ships the character of the curve is likely to vary. Among the controlling circumstances which chiefly need attention are:

1. The area of the rudder, the maximum angle to which the helm can be put over, the rapidity with which it can be put hard over.
2. The speed of the ship or that of her propeller, as well as other causes influencing the flow of water relatively to the rudder, and the consequent development of an unbalanced pressure on the rudder, which exercises a turning effect on the ship.
3. The moment of inertia of the ship taken about a vertical axis passing through the center of gravity of the ship.
4. The moment of the resistance offered by the water to the lateral, rotary, and endwise motions of the ship.

It would be out of place for me to give any explanation of the causes which produce and determine the magnitude of the pressure on the rudder, since the matter is fully discussed in text books of naval architecture. Moreover, the ship comes into the hands of her commanding officer furnished with her rudder and steering gear, which have been tested in the constructor's trials. Experience may suggest improvements, of course; but, as a rule, the changes made are not great, and consequently in the management of the ship an officer can take advantage only of variations in the helm angle below a certain fixed maximum, and of variations in speed or direction of motion. It is generally agreed that—

1. Other things being equal, the turning effect of a rudder increases with an increase in the helm angle up to 40° or 45° with the keel line.
2. Other things being equal, the rate of acquisition of angular velocity, or the rapidity with which a ship turns, increases as the time occupied in putting the helm hard over is diminished.

Hereafter I shall mention a case or two illustrating the effect of putting the helm over more quickly upon the turning of ships; but as illustrations of the advantages of large helm angles, I may quote at once a few figures from actual trials. Admiral Sir Cooper Key found that the Delight gunboat behaved as under, when the helm angle alone was varied:

Helm angle.	Time of turning full circle.	Diameter of circle.
°	′ ″	*Feet.*
10	3 52	615
20	3 18	405
30	2 57	275
40	2 47	205

Admiral Halsted, in the trials conducted with the floating battery Terror, obtained the following results:

Helm angle.	Time of turning full circle.
°	′ ″
10	6 19
20	5 28
30	5 1
40	4 42

Lieutenant Coumes, of the French navy, gives the following results for the iron-clad corvette Victorieuse, for an initial speed of about 12½ knots:

Helm angle.	Time of turning full circle.	Diameter of circle.
°	′ ″	*Meters.*
7	9 48	1,060
14	6 50	933
21	5 50	750
27	5 20	572
32½	5 20	475

Respecting the remaining circumstances enumerated above as affecting the turning motion, a very few remarks will suffice. In arranging the longitudinal distribution of the weights in a new ship, the naval architect cannot be governed by consideration of the effect which the *moment of inertia* has upon the turning qualities. But it is well known that if the weights are carried far away towards the ends of a ship, and her moment of inertia is great, she will be *slow* to *answer her helm*, as compared with a ship of similar form and equal displacement, having the weights more concentrated towards the middle of the length. Again, as regards the effect of fluid resistance, which depends largely upon the under-water form, no designer can be much influenced in deciding upon the form of a ship by considerations relating to resistance to turning. He has to consider ease and economy of propulsion before these minor matters, and can only make changes of a subordinate character, such as cutting up the fore-foot, or raising the after end of the keel, in order to diminish somewhat the resistance to turning. On the other hand there are cases, and particularly in ships of shallow draft and full form, where difficulties arise from the fact that they experience so little resistance in turning. For while resistance opposes change in the course of a ship, it also enables her to be easily kept on a new course when her head has been brought round to it. Probably I speak the experience of many naval men in saying that the ships most difficult of management are vessels of great inertia and shallow draft. At first such vessels may be slow to answer their helms, but when once the angular motion has been established it is most difficult to check it, because of the comparatively small resistance. The Russian circular ships are reported to be very difficult to manage; and clearly the principal reason for their uncertain behavior must be found in the association of a large amount of inertia with a very small resistance to rotation, due chiefly to skin friction. If the inertia and resistance are both small, as happens in shallow-draft gunboats, the vessels quickly acquire angular motion after the helm is put over, but "sheer" off sideways from the course on which their keel line points, because of the small amount of their lateral resistance. These are a few among many of the illustrations that might be given of the fact that some classes of ships have their turning powers affected by their special features, modifications in which are inadmissible. In such cases careful management is of the greatest importance, and enlarged experience leads to improved behavior and greater certainty in control.

Although the true character of the path traversed by a ship in turning has been determined in very few cases, it is known that it is more or less spiral up to the time that uniform angular velocity is reached. This departure from a true circle is of the character indicated in Fig. 3, and it places the ship, when she has turned through 360° and is again pointing in the original direction, somewhat to port or starboard of the original course, according as the ship is turning to port or starboard. The space occupied in turning through 180° and reversing the course has been termed the tactical diameter (*diamètre d'évolution*); it considerably exceeds the diameter of the circular orbit in which the ship turns after her motion has become uniform, or "final diameter" (*diamètre de gyration*). The reason is obvious; in the earlier part of the turning motion of the ship she is acquiring angular motion, that is to say, is subject to angular acceleration, and the curvature of her path is less pronounced than it is in the subsequent stages. It may be interesting to illustrate the ratio of the tactical and final diameters by a few figures drawn from actual trials:

	Helm angle.	Speed on straight.	Diameters.	
			Tactical.	Final.
	°	*Knots.*	*Feet.*	*Feet.*
Thunderer (English)	31	8.2	1,405	1,340
		9.4	1,320	1,250
		10.4	1,320	1,240
Victorieuse (French)	33	10.0	1,440	1,230

At present the published information on the ratio of tactical to final diameters is very limited; it is a subject to which further experiments may well be devoted. But for all practical purposes the determination of the tactical diameters is the more important. In the constructors' turning trials the diameter of the circle, as usually determined, is practically the tactical diameter, as will appear from the description given hereafter. With manual power and ordinary rudders the diameter of the circle for large ships has been found to vary between six and eight times the length of the ships; for small ships, wherein manual power suffices to put the helm over rapidly and the speed is low, the diameter falls to three or five times the length. For swift torpedo-boats, with manual power only at the helm and very small angles of helm, the diameter of the circle for full speed has reached about twelve times the length, and for half speed about four or six times the length. With manual power and *balanced* rudders the diameter for large ships has been reduced to four or five times the length; and nearly equal results have been obtained with ordinary rudders worked by steam or hydraulic steering gear. About three times the length is the minimum diameter yet obtained in large ships turning under the action of their rudders. These figures apply chiefly to full-speed trials; but it appears that differences of speed do not greatly affect the diameter of the circles, although they do affect the time of turning, so long as the time occupied in putting the helm hard over is nearly constant. For the same ship with the same angle of helm, and about the same time occupied in putting the helm over, the time occupied in turning the circle appears to vary nearly inversely as the speed. The time occupied in putting the helm hard over considerably affects the time of turning, and also influences the diameter of the circle. In the case of one of Her Majesty's ships, where the conditions remained almost unchanged, except that a steam steering engine was fitted, and the time occupied in putting the helm hard over was reduced from 90 seconds to 20 seconds, the time occupied in turning the circle was reduced from 8½ minutes to a little over 7 minutes, and the diameter of the circle was reduced from 970 yards to 885 yards. Before steam steering engines became common in the Royal Navy balanced rudders furnished the best means of putting a large rudder area over quickly to a large angle, and the Bellerophon, Hercules, Monarch, and other vessels so fitted performed admirably in turning under steam. But now that mechanical steering appliances are available, ordinary rudders, hinged at their fore edge, are once more preferred, because they are simpler and less liable to derangement than balanced rudders, besides being more suitable for use in ships having sail as well as steam power.

The determination of the tactical diameter is an important matter, but it does not furnish a complete or sufficient account of the space necessary for a ship to reverse her course; for it gives only a measurement at right angles to the original course—which may be termed the "transfer" of the ship—and affords no measure of her "advance" in the direction of her original course. Taking the case of the Thunderer (Fig. 3), it appears that, reckoning from the instant when the helm began to move over, the ship *advanced* about 1,000 feet in the direction of her straight course before her head had swung through 90°, and was *transferred* (at right angles to her course) about 700 feet. When her head had turned through 180° and the course was reversed, the *advance* had been reduced to 520 feet, while the *transfer* (or tactical diameter) had increased to 1,320 feet. It is most important to ascertain the advance and transfer for the 90° position; the necessary observations are easily made, and I shall not occupy space with a description of any one among the many methods that might be used.

Passing from these general considerations, I will now endeavor to sketch briefly the methods adopted for measuring the diameters of the circles turned by ships on their constructors' trials.

The first is that commonly used in trials of Her Majesty's ships; it was introduced about fifteen years ago by Mr. Martin, chief constructor of Pembroke dock-yard, and is illustrated by Fig. 4.

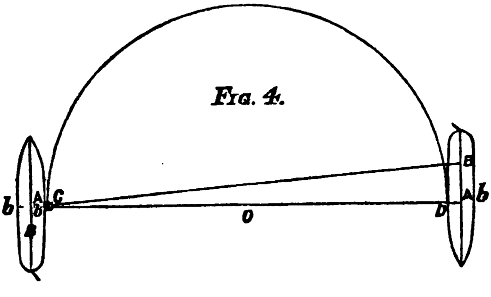


Fig. 4.

At any assigned place in the length of the ship two vertical battens, *b*, *b*, are fixed in the same transverse plane, and an observer is stationed at the position fixed by one of these battens. A second observer is stationed at B, at a certain longitudinal distance, *l*, from the first observer, and this second observer has to operate a very simple instrument for measuring angles, which is shown on a larger scale in Fig. 5.

The zero line of this measuring instrument is made to coincise with, or be parallel to, the middle line of the ship. When the helm begins to move over, a box, C, is thrown overboard from the station b, at which the fixed battens are placed. After the ship has turned through such an angle that the line joining the two fixed battens again bears upon the box C, a signal is made to the second observer, who instantly notes the angle (ABC) which the line of sight to the box C makes with the zero line of his measuring instrument; let this angle be termed a. Then a simple trigonometrical ratio gives—

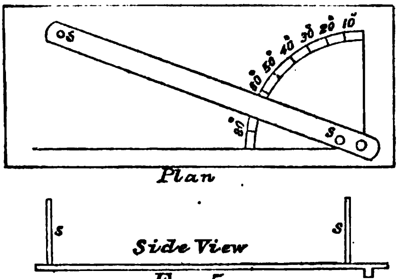


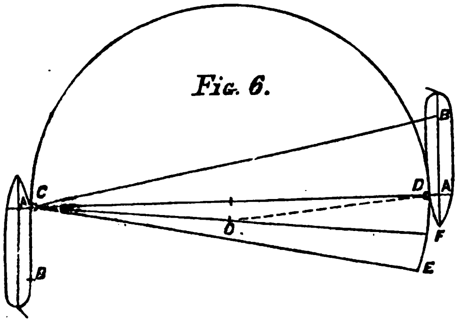
Fig. 5.

$$\text{Diameter of circle} = l \tan a,$$

if the semicircle is supposed to be completed when the angle a is measured. This is a good practical method for smooth water and a calm. Obviously it takes no account of a possible drift of the box, and it assumes the omission of the "drift angle" for the ship, on the supposition that the semicircle of rotation is not completed until the line joining CD is a diameter of the circle. As a matter of fact, owing to the creation of the drift angle, the head of the ship will have turned through 180° *before* her center of gravity has traversed so large an arc in its path. The amount of this possible error in most large ships is not great, and for ascertaining the diameter of the circle simply the plan is a good one. It may be added, that since the diameter determined is for the points in the ship at which the fixed battens are placed, by fixing them first at the bow and next transposing them to the stern it would be possible to ascertain the diameters of the respective circles for the bow and stern, and thence to determine the drift angle approximately.

Lieutenant Coumes, of the French navy, has recently published an extension of the English method, which deserves to be widely known. It is illustrated in Fig. 6. He assumes the path of the ship from the straight course to a little beyond the place where she has turned through 180° to be an arc of a circle. At the position C, on Fig. 6, a buoy is dropped overboard abreast the fixed battens, just as is done in the English plan. At the position marked D the head of the ship has swung through 180° and the line joining the two fixed battens bears upon the box at C. An observer stationed at B, at a known distance from the fixed battens, notes the value of the angle, ABC (a), at that instant, and simultaneously a second box, D, is dropped overboard. The ship moves on to a position, E, a little beyond D, and the observer stationed at the fixed battens notes the angle, EDC (β), which the two boxes, C and D, then subtend. These are all the observations needed. Suppose O to be the center of the circular path, join CO and produce it to meet the circle at F, also join DF. Then the angle, DFC, is equal

Fig. 6.



to β, being in the same segment, and the angle, CDF, being in a semicircle, is a right angle. Hence—

$$\text{Diameter of circle} = \text{CD} \times \text{cosec } \beta.$$
$$\text{Diameter of circle} = l \text{ tan. } a \text{ cosec } \beta.$$

Further, it will be seen that the drift angle (δ), equals the angle CDO, which is equal to DCO, and is therefore the complement of β.

The maximum correction produced by substituting Lieutenant Coumes' method for Mr. Martin's in estimating the "tactical diameter" is expressed by the product of the radius into the versed sine of the angle of drift, or algebraically—

$$\text{Error} = \text{radius} \times \text{versine } \delta,$$

where δ varies between 10° and 20° and versine δ varies between .015 and .06. This correction is evidently of little importance in most cases.

Another plan, which has been extensively used in estimating the diameter of the circles turned, is to tow a patent log astern and note the distance it registers while the ship turns through 360°. This registered distance is afterwards treated as the circumference of a circle, and the diameter is obtained by a simple calculation. Opinions are divided as to the trustworthiness of this plan. I do not pretend to be in a position to decide the matter, but feel confident that the chances of error must be greater than in the geometrical methods above described. Even with the best logs available towed behind a vessel moving at a varying speed and turning, there must be great danger that their indications will vary with differences of speed or will be affected with the wake of the vessel. The French have made comparative trials of the geometrical method and of log-measurement, the result being unfavorable to the latter.

Still another plan, well adapted for small vessels, is that devised by Sir Cooper Key and used in the turning trials of Her Majesty's gunboat Delight, conducted at Devonport in 1863. The register of a Massey's patent sounding machine was removed from the lead and attached to a long staff. At the commencement of a circle the register was immersed, when the circle was completed it was immediately raised. The distance registered was read off, and this was treated as the circumference of the circle traversed.

In the French squadrons of 1864–'66 the turning trials were conducted differently from any of the foregoing methods. Captain Bourgois gives the particulars in his pamphlet previously noticed; it may be briefly described as follows: One ship of the squadron was anchored, and the vessel whose movements were to be recorded turned about the stationary vessel. Two observers were stationed at a known distance apart on board the moving vessel. At frequent and regular intervals of time these observers noted simultaneously and recorded the angular elevation of a mast head in the anchored vessel. The height of this mast head above the water being known, this series of observations gave the distances of the anchored ship from each observer at each time of observation. Meanwhile observers stationed on board the anchored vessel took frequent and simultaneous observations of the angular elevations and bearings of a mast head in the ship that was turning. And further, other observers on board the moving ship noted at frequent intervals the angles subtended by a mast in the anchored ship with some fixed and distant object. These observations would have sufficed to determine the path traversed by the ship from the time her helm was put down; but it is a remarkable fact that the important motions of the ships through the first 90° of rotation were designedly neglected, and the observations were begun only when approximately uniform circular motion had been attained. On the other hand, it is in these records one finds attention first given to the importance of determining the drift angle.

The French appear to attach great importance to the determination of the tactical diameter corresponding to various revolutions of the screw and various helm angles for individual ships. I leave naval officers to say what this knowledge may be worth in its bearing upon the movements of the ships composing a squadron; but it is obvious that if the ships are of various sizes and types, combined movements under steam can be performed with greater uniformity if the admiral has this kind of information for all the ships under his command. Perhaps it may be as well to add that the plan which has been sometimes adopted for estimating the diameter of the circle turned by counting the revolutions of the engines, and thence deducing the speed, is liable to lead into serious error. Owing to the drift angle the speed corresponding to a given number of revolutions is much less when a ship is turning than it is when she is on a straight course. In the Thunderer, for example, a speed of 10.4 knots was obtained with 65 revolutions, whereas on the circle 59 revolutions only gave a speed of 7.14 knots.

In concluding these remarks on methods of recording the behavior of ships when turning, I may be permitted to add that in the trials with the Thunderer the method of procedure embraced many of the foregoing principles, and enabled a most searching check and counter-check to be put upon the observations. Any officer familiar with nautical observations will find no difficulty in arranging his own programme should he decide to accurately determine the path of his ship in turning under certain assumed conditions. But he can only derive benefit from a study of what was done in the Thunderer, the report of the trials of that ship containing the most thorough information yet published on this subject.

It is impossible to discuss the "Turning Powers of Ships," even in the outline to which I am compelled to confine myself in the present paper, without referring to the maneuvering power given to a ship by *duplicate propellers*, and more especially by twin screws. Twin screws are now almost universally adopted in the most powerful war ships, and their efficiency as propellers is well established. But they have the further advantage of enabling a vessel, by reversing one of her screws while the other drives her ahead, to turn in a very small circle—almost in her own length. The rate of turning under these circumstances is often slow, but the power of giving rotation to a ship practically destitute of headway and independently of the rudder is of great value. Twin screws are, of course, associated with rudders, and no one at all conversant with the subject would propose to trust to twin screws alone for maneuvering purposes. They are really only valuable auxiliaries to the rudder, and in no sense rivals to it.

Beside twin screws are disconnecting paddles and water jets which come under the category of duplicate propellers, giving maneuvering powers to ships. Paddles are, however, out of the question in men of-war. From water jets considerable maneuvering power was expected, but the trials of the jet-propelled Waterwitch in competition with the twin-screw Viper showed the distinct inferiority in this respect of the jet propellers. Moreover, it is evident that so far as the trials of water jets have been carried they are decidedly inferior to twin screws as propellers. Under these circumstances, it appears reasonable to adopt twin screws, as the remaining arguments urged in support of the use of water jets seem comparatively unimportant. I express this opinion after careful consideration of what has been said respecting the enormous pumping power obtained from the turbines, and of the little risk of serious damage being sustained by jet propellers. But it would be out of place to say more on these subjects in this paper.

The Waterwitch and Viper are of nearly the same length, and were tried at as nearly as possible the same displacement, draught, and speed. The Waterwitch is a "double-bowed ship," the intention being that she should be equally capable of steaming with either end foremost; she has a rudder at each end, but on the trials only that at the after end was used. The Viper is a vessel of very different form, her stern being formed with two dead-woods, each of which carries a rudder. She gains upon the Waterwitch by having this additional rudder, but loses very seriously in having a tunnel-shaped cavity between the dead-woods, which interferes both with her propulsion and with her maneuvering. When steaming full speed ahead with rudders hard over, the times for turning the circle were—Viper, 3 minutes 17 seconds; Waterwitch, 4 minutes 10 seconds. With one screw reversed and the other turning ahead, helm hard over, the Viper took 3 minutes 6 seconds to turn the circle; while the Waterwitch under similar conditions—with jets delivered in opposite directions—took 6½ minutes to turn the circle. Even allowing for the additional rudder in the Viper, these results speak strongly in favor of the twin screws. I am informed by gentlemen who attended these trials that there were evidences in the Waterwitch of a reaction of the jets against the sides of the vessel adjacent to the outlets, which reaction had a moment opposing the turning moment due to the thrusts of the jets. And on *à priori* grounds such a check to the turning motion seems probable, and may become considerable.

It may be interesting to add, with regard to the turning effect of twin screws when working in opposite directions, that in deep-draft ships the time occupied in turning is usually greater than the time for turning the circle with both screws working ahead at full speed; whereas for shallow-draft ships the corresponding difference in time is small. For example, in the Captain, the time for circle at full speed ahead was 5 minutes 24 seconds; that for circle with screws working in opposite directions, 6 minutes 52 seconds. In the shallow-draft gunboats of the Medina class, on the other hand, the full-speed turning trial gave about 3 minutes 6 seconds for the circle, and with screws working in opposite directions the time was only 3 minutes 13 seconds. It will be obvious that in the shallow-draft ships the ratio of the moment of resistance to rotation to the turning moment of the screws is much less than the corresponding ratio for deep-draft ships.

Trustworthy data are much needed respecting one feature in the steerage of twin-screw ships. It is well known that with one screw only at work a small angle of helm will keep a twin-screw ship on a straight course; and this is a proof of the moderate turning moment obtained with twin screws working in opposite directions. But I have searched unsuccessfully for records of exact experiments determining what angle of helm suffices to balance one of twin screws working alone; and I shall be much indebted to gentlemen who may be good enough to give me the needed information. The facts to be noted are very few and simple, viz: (1) the revolutions of the screw; (2) the speed of the ship; (3) the angle of helm required to keep the vessel straight.

When I speak of the moderate turning effect of twin screws, it will be understood that I have in mind the corresponding effect of even a small rudder at a small angle, in a ship steaming at full speed ahead. The normal pressure on such a rudder will be considerable when compared with the thrust of a screw; but the greatest gain for the rudder pressure is the *leverage* with which it acts. Roughly speaking, this leverage is equal to the product—*half length of ship* × *cosine of helm angle;* whereas for the twin screws the corresponding leverage is only about equal to the tranverse distance between the screw shafts, or less than one-half the extreme breadth of the ship. It must not be forgotten, however, that for the rudder to act most efficiently, a ship must have good headway; whereas in the twin-screw ship there is a possibility of turning with very little motion ahead.

The steering effect of a single screw, which has the greatest practical interest, is that in ships where the rudder is placed abaft the screw. It is well known that, in such cases, if the screw be turned ahead or astern when a vessel is at rest, the impact of the screw race upon the rudder will give steerage power before the vessel has acquired sensible headway. By this means it is possible to slew a single-screw ship round in a very limited space in calm weather, although the operation is a very tedious one. But there is another steering effect of a single screw independent of the rudder, with which sailors are familiar; I mean the effect which produces a turning motion in a ship of which the helm is kept amidships while the screw revolves. The principal causes of this turning motion are (1) the difference of the transverse thrust on the blades of the screw in the upper and lower halves of their orbit; (2) the difference in the lateral pressures, due to the momentum of the streams delivered by the upper and lower blades of the screw upon the stern-post and body of the ship. The ordinary result in ships of the royal navy is that with *well-immersed* screws, the head of the ship turns in the same direction as the *upper* blades of the screws move; but that with screws which are near the surface, or which sweep above the surface, the contrary holds good, and the head of the ship turns in the direction in which the lower blades are moving. I am aware that there are exceptions to these rules, but think they generally hold good for ships moving *ahead.* When the screws are turning astern, the conditions are altered materially; but I cannot pause to discuss this division of the subject. Hereafter I shall again refer to it briefly.

Various attempts have been made to derive steering power from *single screws* by mechanical arrangements enabling the screws to deliver their thrust at an angle with the keel line. One of the first of these was that proposed by Mr. Curtis, and tried at Devonport some years ago. The screw was carried in a frame hinged like a rudder, which could be put over to a considerable angle with the keel. A suitable joint was provided so that the fixed shaft could communicate rotary motion to the screw in any position. The plan succeeded well so far as steering power was concerned, but it was felt that this power was purchased at too great risk of disablement of the propelling apparatus for large ships.

Recently, a most ingenious plan for effecting the same object has been patented by an American, Colonel Mallory, who has devised a method for rotating the screw through a complete circle, and meanwhile keeping the main engines running continuously in one direction. A boat fitted with the Mallory propeller (see plate) can be turned almost on her center, stopped very rapidly, and kept thoroughly under control by the action of the screw alone, no rudder being fitted. No trials on a large scale have been made, but it is clear that difficulties which can be readily surmounted in a boat may become very formidable in a large ship with great engine power and high speed. Risks which may be run in boats and small vessels may also become too great when applied to sea-going ships of war. There are mechanical difficulties connected with the Mallory propeller if used in large vessels, to which I need not here draw attention, my object being simply to indicate the lines along which recent inventions have proceeded.

Since mechanical steering gear and twin screws have come into general use for large war ships, their maneuvering powers have been so greatly increased that few trials have been made of plans for further improvements. But in connection with the fast torpedo boats which have grown rapidly into importance, many trials of novel or improved steering appliances have been made which would of themselves form the subject of a most interesting paper. These torpedo boats, on account of their great engine power, high speed, and shallow draught, are found to sweep over a comparatively large space in turning. Their designers have not failed to remark the disadvantages resulting from their comparative unhandiness, nor have they been slow to attempt a remedy. In the Herreshoff torpedo-boat, built in America, and purchased for the royal navy, both the screw and the rudder are placed under the bottom of the boat, and the results are very satisfactory, both as regards propulsion and steering. Going either ahead or astern, the boat can be turned in about three times her length, and when steaming ahead at full speed can be stopped in a very small distance. In a large vessel of considerable draught, I need hardly say, neither the screw nor the rudder could be placed similarly below the keel.

Messrs. Thorneycroft have tried various plans in their torpedo boats, placing the rudders before the screws in earlier boats, and subsequently placing the rudders abaft the screws, with very beneficial results so far as the steering is concerned. Their latest device is a revival of one of the oldest methods, if not the oldest method of steering, by means of a paddle or scull placed at one end of the boat, and operated by a most ingenious mechanical arrangement. This plan is patented, and answers admirably in the trial boat to which it has been fitted. Its greatest merit appears to consist in the power it gives to slew the boat round without headway, and to keep her pointing at an enemy even when the main engines are at rest. In a torpedo boat this power seems of the greatest importance. Messrs. Yarrow have also availed themselves of an old idea, applying it to torpedo boats in a very ingenious manner. Besides the ordinary rudder at the stern, they have fitted a bow rudder which can be drawn up into a recess in the boat when not required, or dropped below the bottom and put over to a considerable angle with the keel line when it is to be used for steering. On trial it has been found a valuable auxiliary to the stern rudder when the boat is moving ahead, and a very efficient rudder when the boat is moving astern.

I may be permitted to remark, in passing, that the trials of both Messrs. Yarrow's boats and the Herreshoff boat have fully confirmed the opinion respecting bow rudders held by naval architects previous to the trials. In order that a bow rudder may be effective in steering a ship which is moving ahead, there must be a free flow for the water past the aft side of the rudder, without any necessity for its impact upon the hull of the ship. When a bow rudder is hung, as is usual, at the after edge to the stem of a ship, this condition is obviously unfulfilled. On the other hand, a properly arranged balanced bow rudder, or a bow rudder placed below the hull, will fulfill the conditions. Bow rudders are, however, chiefly useful in ships designed for service in rivers or narrow waters, where it is frequently convenient to steam with the stern foremost instead of turning.

Auxiliary rudders of many kinds have been proposed and tried. In the museum of naval models at the Royal Naval College, Greenwich, a good collection of these plans may be seen, and it shows how frequently an invention is reinvented by persons who have the same object in view, but are working in ignorance of what has been done by their predecessors. I have only space to allude to the most recent and most successful trials of auxiliary rudders made in the Comus class of the royal navy. These vessels have an ordinary rudder at the stern, and an auxiliary rudder fitted in a recess in the after part of the hull below the screw shaft. This auxiliary rudder has side plates fitted at some distance from the body, on the plan proposed by M. Jöessel, of the French navy. On trial it was found to answer fairly, keeping the vessel under control, although its effect did not compare favorably with that of the main rudder; nor was this anticipated, since the rudder is fitted as an auxiliary only for use when the main rudder is disabled in action.

The steerage of a screw steamship having engines reversed, while she has either *headway* or *sternway*, supposing her to be fitted only with an ordinary rudder at the stern, is a subject for experimental inquiry rather than for mathematical investigation. It is easy to see what causes are in operation tending to control the behavior of the vessel; but these causes are so conflicting and variable as to make any general statement of little value. The following extract from the report of the committee appointed by the British Association "to investigate the effect of propellers on the steering of vessels," may be read with interest, as it represents the conclusions reached after a considerable number of experiments had been made by Prof. Osborne Reynolds and other members of the committee:

> It appears both from the experiments made by the committee, and from other evidence, that the distance required by a screw steamer to bring herself to rest from full speed by the reversal of her screw is independent, or nearly so, of the power of her engines, but depends upon the size and build of the ship, and generally lies between four and six times the ship's length. It is to be borne in mind that it is to the behavior of the ship during this interval that the following remarks apply.
>
> The main point the committee have had in view has been to ascertain how far the reversing of the screw in order to stop a ship did, or did not, interfere with the action of the rudder during the interval of stopping; and it is as regards this point that the most important light has been thrown on the question of handling ships. It is found an invariable rule that, during the interval in which a ship is stopping herself by the reversal of her screw, the rudder produces none of its usual effects to turn the ship; but that under these circumstances the effect of the rudder, such as it is, is to turn the ship in the opposite direction from that in which she would turn if the screw were going ahead. The magnitude of this reverse effect of the rudder is always feeble, and is different for different ships, and even for the same ship under different conditions of lading.
>
> It also appears from the trials that, owing to the feeble influence of the rudder over the ship during the interval in which she is stopping, she is then at the mercy of any other influences that may act upon her. Thus the wind, which always exerts an influence to turn the stern (or forward end) of the ship into the wind, but which influence is usually well under control of the rudder, may, when the screw is reversed, become paramount, and cause the ship to turn in a direction the very opposite of that which is desired. Also the reversed screw will exercise an influence which increases as the ship's way is diminished to turn the ship to starboard or port, according as it is right or left handed; this being particularly the case when the ships are in light draught.
>
> These several influences, the reversed effect of the rudder, the effect of the wind, and the action of the screw, will determine the course the ship takes during the interval of stopping. They may balance, in which case the ship will go straight on; or any one of three may predominate and determine the course of the ship. The utmost effect of these influences when they all act in conjunction, as when the screw is right handed, the helm starboarded, and the wind on the starboard side, is small as compared with the influence of the rudder as it acts when the ship is steaming ahead. In no instance has a ship tried by the committee been able to turn with the screw re-

versed on a circle of less than double the radius of that on which she would turn when steaming ahead. So that even if those in charge could govern the direction in which the ship will turn while stopping she turns but slowly, whereas in point of fact those in charge have little or no control over this direction, and unless they are exceptionally well acquainted with their ship they will be unable even to predict the direction.

There is much in these conclusions which has been well known for many years to men engaged in handling screw steamers; and trials were made in the Great Britain to determine the effect of the screw race upon the steerage. But no one can look through the reports of the committee from which the above quotation is made without feeling that their experiments are very valuable and deserving of being carefully studied by all officers in command of screw steamships. Differences of opinion which exist as to the wisdom of some of the recommendations for avoiding collisions made by the committee will not prevent any one interested in the subject from acknowledging the great merits of the work done by the committee, or at its request.

Throughout this paper it has been assumed that the ship's maneuvering capabilities are ascertained in smooth water and in a calm or light breeze. These are the conditions most suitable for exact experiments and comparison; but I need hardly say that such trials do not represent the conditions of actual service. It would be idle to attempt any discussion of the influence which the wind and sea have upon the turning powers of ships, since that influence is so variable. But, on the other hand, it must be remembered that the principles previously laid down for turning in smooth water hold good also in a seaway; only the effects of the rudder, of the inertia, and resistance are then supplemented by the effects of wind and sea. This branch of the subject is, in fact, one of seamanship, and not one to be discussed by the naval architect.

The general conclusions to which my study of the subject of this paper has led me may be briefly summarized as follows:

(1.) On the whole, the ordinary rudder hung at the stern of a ship has not been equaled for maneuvering purposes when a ship has *headway*.

(2.) When associated with steam or hydraulic steering gear the ordinary rudder hinged at its forward edge to the stern-post is to be preferred to all other kinds of rudders. Balanced rudders are chiefly useful, if mechanical steering gear is not available, in large ships.

(3.) Twin screws furnish the best combination of economical propulsion with maneuvering power which has yet been produced.

(4.) The various inventions hitherto tried for rendering the thrust of a single propeller available for maneuvering purposes involve risks and drawbacks too serious to be encountered in large ships, although the contrary may be true in small crafts.

(5.) Bow rudders are chiefly useful to assist steerage in ships moving astern. Balanced or "drop" bow rudders are to be preferred for use when ships are moving ahead.

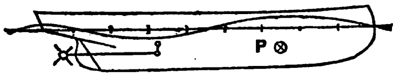
(6.) It is desirable that further and careful observations shou'd be made of the actual behavior of ships when turning at various speeds and with different helm angles. Accurate plottings of the path traversed while the head of the ship swings through the first 90° from her original course are especially needed.

I must apologize for the many omissions which have necessarily been made in the treatment of this important subject. My aim has been to have regard chiefly to that which is practically interesting and important, and I shall be amply repaid for the labor involved in preparing this paper if any of the suggestions made for further experiments should be carried out in practice by officers into whose hands the paper may come.

Captain LONG, R. N. After the kind manner in which Mr. White has referred to me, I feel compelled to rise to offer some observations on his paper. It is not for me to compliment Mr. White, but I cannot rise without expressing my sincere gratitude to him, which I believe is shared by every officer in Her Majesty's Navy, for the trouble he has taken to convey food to what I may call our hungry minds. Mr. White in his book states that the action of the screw on the rudder was known in 1845. Now, I have been 20 years in sea-going ships, and I have never heard that fact mentioned. That shows either that I must be very negligent in learning my duty or that the Service does not offer that means of obtaining information which it ought to afford. That I consider a matter of very great importance to this country. We are often told that theory is pernicious, but the fact is, the experience of a naval officer in peace time is so totally different to what it would be in war time, that I do not think any argument would be founded upon it. During peace time we are supposed to take the greatest possible care of our vessels, to avoid the slightest risk, and to go at the most economical speed. The expense involved prevents many of the real circumstances of war from coming before a naval officer unless he takes the trouble personally to seek them. As to the action of twin screws on the rudder, I have heard from the staff commander of the Thunderer that the Thunderer sometimes appears to be lost control of by her helm—she appears to move suddenly, and to require the whole helm to prevent her going right off; and he attributes it to the screws turning outwards. I am not sufficiently acquainted with the subject to tell whether that is practically correct; but I should like to ask Mr. White whether he knows any reason why they should turn outwards in preference to turning inwards. Perhaps also Mr. White can tell us whether we are likely to obtain any information of the probable effect in reducing a ship's turning power that would be produced by a water-tight compartment, or two water-tight compartments getting full at the extremes, because in action that is very likely to happen. Perhaps her two bow compartments would be full, and in order to estimate what you ought to do under those circumstances, it would be desirable to know beforehand, with some degree of approximation, what reduction of turning power that would cause. I have copied from the British Association report the experiments with the Hankow, which are very interesting, and I will hand them in, in case the council should think proper to append them to the paper. They are corroborative of all that Mr. White has said. I may mention that the azimuth of the ship's head having been noted by the standard Admiralty compass, the arcs turned through could not be taken as being strictly accurate. With reference to Mr. White's observation concerning merchant steamers, I have in that case averaged the angular velocity of the ship when she had obtained the uniform stage, and that was 27′ per second as against 1° 18′ of the Thunderer. She is a vessel of 3,594 tons, 389 feet long, and 42 feet beam, with a draft of water 24 feet 8 inches forward, and 23 feet 8 inches aft. That shows that this merchant steamer, which is no doubt a very representative vessel of trading steamers, only turned when she was under her full helm at one-third the speed of the Thunderer. I was reading M. Coumes' method and also hearing Mr. White's very interesting lecture at Greenwich, that called my attention to the subject of plotting curves, and when I applied M. Coumes's method to the Thunderer's, I could not quite get it out. I found the angle Beta always came so close to 90°, that it did not seem to me to be of any use. What we want to know when we turn a ship is, starting from the point where we give the order to the helm, where we shall be after we have turned through 90° and 180°. We do not care much about anything else, the other parts of it belong more to the naval architects. Of course the difficulty is how to know that you turn through a certain angle If you are near land you can take a distant object at right angles to your course, allowing for parallax, and say, when that is ahead, I shall have turned through 90°; but the convenient times for doing these things are generally when you are a long way off land, and under those circumstances I should strongly recommend Sir William Thomson's compass. I should not like to recommend it entirely on my own responsibility; but I have Sir William Thomson's own words for it that that compass when compensated would register accurate azimuths through a circle, and I also have the authority of the staff commander of the Thunderer, who has had that compass on board 18 months; he speaks very highly of it, and strongly advocates its adoption by all men-of-war. If you had not such a compass, you might get the angles with an ordinary compass brass arc if furnished with a shadow pin standing vertically up in the center of the compass, so that the shadow is thrown on the arc, and by that you could tell the angle you turn through. Of course that would not be available in cloudy weather, so that I think Sir William Thomson's on the whole is the best one. Admiral Bourgois, who has taken great interest in these subjects, says that a table of turning power is no less necessary to a ram than a range table to a gun. That is a very important thing, and I could not conclude these remarks better than by saying that it appears to me in every ship there should be a curve of the diameters by the circles obtained at constant speeds and various helm angles, and also at constant helm angles and various speeds. If these two things were made for every ship we should have a vast amount of information that we do not possess at present.

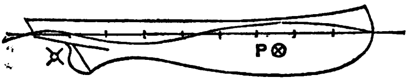
Mr. **Scott Russell.** I am sure I express the feeling of all who have listened to this very admirable paper when I say that we are greatly indebted to the author for the luminous manner in which he has put a great deal of very valuable information together. On these points I do not think I can contribute anything to the value of his paper. There are, perhaps, one or two points on which I rather differ from him, and perhaps it would be best that I should merely state what those points are. I think he has drawn our attention very admirably towards what he calls the "drift" as an element in the steering. I wish to confirm what he has said upon that subject, by very large experience of my own. Having had to build ships that were to turn in extremely small spaces at high velocities, I made all experiments necessary to guide me on that subject, and I very soon made that discovery, which is now incorporated in these papers, namely, that with high velocities, the turning point is not at all the center of gravity of the ship; the turning point is a point a great way in front of the midship section, and that is a subject difficult to understand. I do not say that you cannot make a clear exposition of the causes of it, but I will venture to mention one or two cases, because they show us how we are to get the better of these difficulties. When a ship is going rapidly through the water, in proportion to the rapidity of her motion she raises up a wave of displaced water on each side of her bow, and that wave is a plus or a positive wave rising above the level for the whole length of the bow of a well-constructed ship. On the other hand, in the rear or run of the ship, the water, instead of being heaped up, goes down like that [diagram], but this depends on circumstances and speed. When you attempt to revolve the ship, you have, resisting the turning of the bow, the whole energy of the water which you are striking. Here, then, is a strong reason why the pivoting of your ship, independent of drift altogether, arising purely from difference of pressure, should be very different indeed from a vessel turning round its center of gravity.

Then I go to the next point. I think Mr. White has omitted another element in the turning of the ship, which element is the effect of centrifugal force. I do not put much value on that centrifugal force, excepting under certain circumstances, but there is another power which he did not tell us of, and which, I dare say, he is quite well acquainted with (but it is a serious element), a power of turning the vessel and making her heel, arising from quite other elements. Suppose this [pointing] to be the vertical line in the run of the ship abaft; suppose the rudder put hard over on one side, and suppose the shape of the ship abaft to be the ordinary stern of a ship. Then when he puts the rudder hard over, Mr. White knows very well that it immediately raises a great heap of water on one side to the height due to the velocity with which she is going; and he knows as well as I do that at ten miles an hour, that is a height of 16 feet. That height is of course instigated by the form of the ship, and the angle of helm; but there still remains a portion of that 16 feet, and the rudder turned on one side causes the water at that side to rise to a certain height, which certain height depends on the angle of the rudder, on the speed of the ship, and on the form of the run of the ship. Therefore, there is here a very strong effect upon the vessel, which, when she turns round in a certain direction, makes her heel over so [showing]. That, I think, is an element not to be despised. You may ask, What conclusion do you draw from this? Well, I think that you are obliged to draw several practical conclusions from it. Before I had studied this subject, when I was called upon to make rapidly turning vessels, I was induced, as I dare say many of you have been induced, to think that by cutting off the dead wood of the extremely fine part of the bow, which you can generally do without inconvenience, you would get a much better turning power. I found I got, not a *much* better turning power, but only a *little* better turning power, and the reason is the one I have mentioned, that if the vessel pivoted round very near the stern, then anything you cut off the bow would greatly assist it in turning; but if, on the contrary, the turning point is much nearer the bow than the stern, then in that proportion you get very much greater advantage from what you cut off. Therefore, when I had to build very fast vessels, to turn rapidly under difficult circumstances, I was compelled (which I regretted) to cut away the whole of the dead wood abaft.



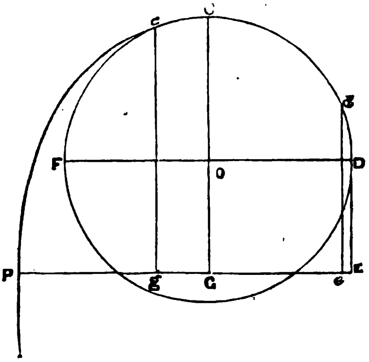
In Fig. 1. the pivoting centre, P, is shown as resulting from the different conditions of the bow water and the run water in an ordinary well-shapen fast ship turning rapidly at high speed; and the screw is shown in the right place for that form and speed of ship.

(*See* diagram 1.) By that means I got the power wanted, and thus removed the pivoting point around which the ship turned, and also removed the part of the ship which had to move round most rapidly, but I got a vessel I very much disliked. There are certain difficulties connected with screw propelling which makes me dislike that, but if I am compelled to do it, if the steering power and the rapid turning power is the most important point in the vessel, then I show you how I do it; I simply send the shaft right through the rudder, and then put the screw on behind. No doubt the screw is much below what you may call the keel of the ship; but I get rid of all the after keel of the ship. I put here exactly what depth I want, and then I put *here* what depth of rudder I want, and *there* what depth of screw I want (see Diagram 2); and in this manner, supposing the water to be as I have shown it here, rising up in a wave behind, and supposing this screw to be judiciously placed, it ought to be very nearly in the centre of the culminating point of this wave in the run. Then you have here a mode of propelling a ship which gives you the greatest possible turning power, without, as far as I know, any sacrifice of any good sea-going quality, or of any speed. I think those are the only points on which I can suggest any difference of opinion from the admirable paper we have just heard, and I thought it my duty merely to contribute that slight difference of view on the matter which may exist between Mr. White and myself.



In Fig. 2, the same vessel is shown, as it was successfully improved in form, so as to gain increased power and quickness of turning.

Capt. P. H. COLOMB, R. N. There are two kinds of papers that we usually have in this institution; one, of the speculative kind, and sometimes those papers are exceedingly useful. At other times, and less often, we have papers of the solid kind, which will be referred to for the next twenty years, as I have no doubt this paper of the lecturer's will be. In my humble opinion there are few questions connected with naval warfare, and I will say also with modern sea traffic, more important than that with which the lecturer has dealt. So long as 120 or 130 ships go to the bottom every year from collisions, so long will it be important to know what the turning powers of ships are, because at the base of the laws on which the avoidance of collisions is to rest lie the actual turning powers of the ship. For ourselves in the navy, I think that the remark of Admiral Bourgois, quoted by Captain Long, is exceedingly to the point. We have introduced into naval warfare a new weapon—the ram. We acknowledge that it is almost the first weapon of future naval warfare, and yet as to the use of that weapon we are comparatively in ignorance, and it is by such papers as this that we are to learn how to use it. Any person undertaking to study the question of the turning powers of ships will be met at once with the difficulty there is in getting data. We have to recollect that this study has grown up since, I may say, about 1863, and I think our gallant chairman is the very first person in Europe who devoted real attention to it, and who produced real facts. We have had to-night reference to the facts obtained by Sir Cooper Key in 1863; and I can say for my own part, having gone over most of the ground which the lecturer has gone over, that I still go back to the record of those experiments of Sir Cooper Key's for data. There is very little indeed in these papers which I should not be prepared to confirm myself, from my own independent investigations. There are some minor points in which I can hardly say that I differ from him, but I think it would be proper to put them forward. They are possibly theories, but they are theories which have struck me as bearing a certain modicum of truth amongst them. I think there is no doubt but that the character of the curve of every steamship is that which the lecturer has given us; that is to say, it is a spiral gradually turning into a circle. The lecturer has put forward, very nearly, the points that naval officers want. They want the position of the ship when she has turned 90°, and the position of the ship measured from the origin of the ordinates when she has turned 180°. I am glad that Mr. White accepts some of my terms, because I think that in a question of this kind it is important to use definitions which everybody will understand. In this curve, PCDF, we can see certain elements. There is first the "tactical diameter," PE, that is to say, the distance between the two courses when the original course is reversed. At the point C, a curve of 90° will have been described, and PG and GC are the coordinates of that point. GC will then be the "advance," and PG the "transfer." Those two lines are evidently the "elements" giving you the position of the ship at C. When the ship has turned 180° and continues her course, we get the tactical diameter. Then, supposing O to be the center of her final circle, you get the line FD as the "final diameter." So far as space is concerned, those would be the elements of the curve, and if we had for every ship the "transfer" and the "advance" in turn-



ing through 90°, and the "tactical diameter," we should have, I think, quite sufficient to satisfy us for some years to come. But there is not a ship afloat, with the exception of the Thunderer, of which we possess those elements. These are all elements connected with space; and you want besides the elements of time. You want to know the time it takes for the ship to pass from P to C, and the time it takes to pass from C to D, and by consequence the time it takes to pass from P to D. If you had those five elements, three of space and two of time, you would have pretty nearly all that we should require. But you are met by a difficulty when you come to investigate the question—there have been many different methods of measurement. Even at the present time, I believe that if we were to investigate closely we should find that sometimes with our own ships there would be differences of measurement at different points which would to a certain extent mar any comparative results between them; and when you come to compare French ships with English ships you find in the same way that you cannot get the accurate elements for forming a just comparison. Practically, unless you know how the measurements were made, it is not of very much use to compare the figures which are given as to the turning powers of any two ships. The "drift angle" the lecturer adverted to first, and quite rightly, because it is the important part of the whole business. We are assuming in this diagram that there is no drift angle, that is to say, that when the center of gravity of the ship has turned through a path of 90° angular distance the line of keel has also altered 90°, but we know now that, owing to the drift angle, this will take place some time before the center of gravity reaches the point C. The time at which the final drift angle is reached is unfortunately not quite satisfactorly made out in the Thunderer diagrams; but supposing it is 10° at the point *c*, the ship will have turned through 90° there, though the center of gravity has only described an arc of 80°. The consequence is you will get an advance and a transfer so much less than if there were no drift angle, and you will get the advance in relation to the transfer increased; that is to say, in turning 90° with a drift angle your spirality is greater than it would be without a drift angle. The drift angle would chiefly affect the transfer; it reduces it in the ratio of the *sine* of the drift angle. It does not reduce the tactical diameter to the same extent, acting on it in the ratio of the versine of the angle, and this may be one of the reasons why we have not noticed it. We have measured either the final diameter, or the tactical diameter, and neither is much affected. If we had been in the habit of measuring the "advance" we should have detected the drift angle before this.

Passing from this we come to the next point, the loss of speed. It is curious that M. Lewal, of the French navy, calculated that there must be a drift angle, from the fact of the observed loss of speed. He found a measure of loss of speed of ships in turning, and came to the conclusion that the rudder itself could never produce that amount of loss; and he thereupon actually calculated the drift angles of French ships from their loss of speed in turning, and those calculations were in the main corroborated by subsequent experiments. But the loss of speed itself does not prove a drift angle. You can easily see that, if you recollect that the power employed is the same throughout, a certain number of revolutions of the engines. If you employ some of these revolutions in turning the ship, it is obvious that you must take them away from propulsive effect. You cannot have the same amount of propulsion through the water when some of the power of the engines is absorbed in turning the ship. But M. Lewal found that this would not account for all the loss of speed, and from the excess of loss he calculated the drift angle. In the paper Mr. White has given the loss of speed at from two-tenths to three-tenths. That is so, I think, in the Thunderer, but in Sir Cooper Key's experiments with the gunboat it was very much more. The loss of speed was 45 per cent. with a 30° helm angle, and 63 per cent. with a 45° helm angle. These figures are perhaps not quite correct, but still I think you may certainly take it that you will find ships with a very much greater loss of speed than from two-tenths to three-tenths. Wanting these elements for your purpose, the next point is, I think, some common and simple method of measurement, and I do not know that there is any better method than to take what was done in the Thunderer. If you take three observers in your ship and have two graduated arcs, such as are figured there from Mr. Martin's plan with a given base between them, one towards the stern and the other towards the bow of the ship, and if you have besides a dumb compass set off from the middle line of the ship, then if you drop a buoy or target (it would be very conveniently done after target practice) and pass it, or steer towards it at any distance, so that you may make sure of turning round it in your circle, if then you take observations of it with your two graduated arcs, those observations being timed by the observer at the dumb compass, who is either taking bearings of the buoy or else at a distant object; if you get a pair of observations at the point P, another pair of observations when the ship has turned through 90°, and another when the ship has turned through 108°, you will get the actual position, by calculation, of the line of keel at those three points. Having that, it seems to me that you will, knowing what we know of the nature of the curve, be able to plot out, quite sufficiently for all your present tactical purposes, the elements of your curve.

The lecturer dwelt on the question of "heeling." That was more by the way than from its tactical importance; but I think, recollecting that we must constantly prepare broadsides for firing when the ship is on the straight, and on an even keel, and that you must fire them when the ship is under the influence of her helm, it becomes of very considerable importance that we should know what heel we should have to expect at differences of speed with different helm angles, and lay the guns accordingly. I do not think this is a matter by the way at all. I think it is quite an important element in the problem.

There is a curious anomaly in the Thunderer's turning circles which I have not observed in any other, but which I must presume obtains in all twin screws. All the authorities, so far as I know, are agreed that, though the difference may be small, the diameter of the final circle becomes smaller as the speed is reduced. There is not a great difference between the diameters, but if you take a final circle, at a very high speed, and a final circle at a very low speed, the last diameter will be somewhat smaller than the other; but in the Thunderer you get exactly the opposite result. The final diameters in the Thunderer go on increasing as the speed decreases. If you refer to the "Inflexible" report you see the apparent cause of it. For some reason, the differences of revolutions in the two screws vary according to the speed. At the high speed the difference of revolution between the inner and outer screw is very considerable, so that you have not only the action of the rudder, but the action of the difference between the outer and the inner screw assisting to turn the ship. When you come down to a low speed, at 8.2 knots, the difference between the revolution of the screws is very small, consequently you are then depending to turn the ship on the rudder solely, without any assistance from the screws. It is a curious fact, and deserves to be noted. It bears out perhaps what we have always been accustomed to regard as the fact, namely, that in single screws the final diameter becomes slightly smaller as you decrease the speed. We have heard it stated that Sir William Thomson's compass might be used in these trials. I have the greatest possible respect for Sir William Thomson's compass. I came home with one in a Peninsular and Oriental ship from Point de Galle. I watched its behavior very closely, and was never so satisfied with a compass in my life. I never saw a compass so beautifully steady. I am told, however, that it was actually put under trial for the Thunderer experiments, and was found to be too sluggish, and failed.

The CHAIRMAN. That was just at the first; it succeeded thoroughly afterwards.

Captain COLOMB. Now there is a very curious point that the lecturer has adverted to, which I want to bring before you specially—that is, as to bow rudders. He puts it that the whole loss of the effect of the bow rudder is due to the fact that there is a reactionary pressure; that whatever pressure is brought on the right surface of the bow rudder is also thrown upon the wrong surface of the bow, and so the action is destroyed. But I think, recollecting that in the Thunderer herself the pivoting point in some cases was only one-seventh of the distance from forward to aft, that is to say, that the lever arm from the pivoting point to the bow was only one-sixth of what it was from the pivoting point to the stern, I think it follows that whatever rudder you put at the bow it is almost impossible it should have much effect. But now Mr. White brings up against that view this peculiar experiment, the effect of dropping a bow rudder below the keel in one of the torpedo boats. It appears on the surface as if it would directly prove Mr. White's case, but I doubt it. Suppose that in Mr. White's diagram (Fig. 1) you have a line of keel of a ship turning on a circle whose center was at O. You have first of all certain pressures along the outside of the ship balancing exactly the tendency to fly from the center, and you may put the whole of those forces as represented by equal and opposite forces acting through the pivoting point. Now, what have you besides? As the ship is turned round in that way you have the pressure of the water against her starboard bow, and you have also the pressure of the water against her port quarter; that is to say, in the first instance you have the pressures balancing the centrifugal force, and then you have the pressures offering resistance to rotation, which are overcome by the effect of the engines and rudder. But now, if you say that she is pivoting on a point very much before the center of gravity, you have a couple formed by the centrifugal force through the center of gravity, and the resultant of the pressures on the outside of the ship. Now, if you by any means increase the surface before this pivoting point, you immediately transfer that point further forward; you increase the length of the arm of your couple, and you increase the moment of rudder power and the velocity of the center of gravity. I cannot help suspecting that without moving the rudder spoken of from its midship position you would still find that you had increased your drift angle, and so got greater turning powers, not due to the action of this as a rudder, but due to its action as transferring the point of resistance further forward, and to increasing the arm of the couple. That is about the only point at which I feel myself at disagreement with Mr. White, and I must frankly own when I began to face these questions mathematically I very soon got out of my depth, but at the same time I cannot help thinking that there is something in my view.

Admiral FISHBOURNE. I do not think that Mr. White has laid sufficient emphasis upon the position and the height of the center of gravity. It has an immense influence in limiting the turning powers. Of course his theory is all right when two ships compared are equally bad or equally good; but it is an essential point that you shall get ships with good turning power. Take the case of the Eurydice. The Eurydice's center of gravity was 2 feet 4 inches above the water line, while the Thunderer's center is nearly 3 feet below. See what a range that involves. As a necessary consequence of being thus high, you get a great inclination, which is very damaging. For fighting purposes it also limits the turning power, and is dangerous. Thus a fine ship in the Mozambique put her helm down and turned over; her center of gravity was very high, she not having taken in sufficient ballast. Mr. White seemed to say that it turned simply upon the height of the metacenter. It depends rather upon where the metacenter height is measured off, whether high up or low down. Again, the draft of water has a very considerable influence on the turning, because if the center of lateral effort of the water is low down, and the center of gravity is high up, there is a long leverage, and the tendency is to increase in the inclination, and limit the power for turning. It is of course very desirable in every ship to have a history of all this, for the ship that has the quickest power of turning is the ship that has the greatest advantage in all evolutions, and she is also the safest ship. A ship which is not entirely under the power of her helm is not a ship at all; she is a danger to herself, and to her neighbors; and the cause of a great number of collisions is, vessels not being under the power of their helms. The contrast will be so great between one ship and another in turning that the cause will, hunted up and corrected, lead to an improvement in naval architecture.

Commander CURTIS. I should like to hear what Mr. White has to say about the balance rudder, because I remember a navigating officer saying, when conversing on the use of bow rudders, that his vessel had two balance rudders; she went from Malta to Corfu with the bow rudder across her, hard over, and they never found it out until they anchored at Corfu. That fully confirms what Mr. White says, that a bow rudder, especially a balance one, has very little influence on a ship when she is going ahead. I was once in command of a gunboat, in June, 1862, the Growler, in whose turning powers I had great confidence.. There was a review at Malta; the Prince of Wales was at Signal Station, with other grandees, and I was ordered to run close under the fortifications of Quarantine Harbor as far as I could. Admiral Codrington ran up the Grand Harbor in Her Majesty's ship Hasty. We steamed full speed close under the fortifications abreast the powder magazine and opposite the packet pier, 84 yards width, where I saw the French packet about to start for Marseilles. I wanted to show off a little, and I ordered the quartermaster to put the helm down as hard as he could; we were under full steam; not having the tiller tackle on, it took four of us to put the tiller over. I ran forward, and to my horror, the vessel did not appear to be turning at all; and I had visions of court-martial and all sorts of things for running the French vessel down. When, however, I turned aft, I found the vessel was like the leg of a pair of compasses, so to speak; she was turning on her fore foot apparently, and I was quite elated. I wished the Frenchman "good morning; good voyage," &c. I could have stepped over the bows of my vessel on to his accommodation ladder when I righted the helm and went on. Any one who knows the Quarantine Harbor at that point will know that there is not very much distance between the packet pier and the rocks under the fortifications; and this appeared to me to confirm what Mr. Scott Russell has said, that the vessel will pivot very nearly on the fore foot.

Capt. J. C. R. COLOMB, R. M. A. I wish to ask a question on the variation of draft, whether or not that variation is an important element in the question? Because I find in a small yacht that it really has a most extraordinary effect. I should also wish to know if there has been any experience to determine the value of a patent log as a means of measurement, that is, comparatively with ascertained measurement by observation.

Captain LONG. I should like to make one remark about the importance of the drift angle. Of course if you know the radius of the circle of turning, and the distance between the pivoting point and the center of gravity, there is no difficulty in reducing the drift angle,

The CHAIRMAN. I trust that this paper, which will be a very valuable addition to our journal, may have some effect in inducing those in authority to give us the opportunity of having experiments tried on the turning powers of various classes of ships. If those that have been tried in the Thunderer are followed out they will be of very great importance to the service, and I have no doubt that the influence which Mr. White undoubtedly has in his own department will enable him to get these experiments carried out. The Service would be much gratified if they could be. It is impossible to overrate the importance of this question of turning power, bearing in mind that in a fleet the whole movements of the ships composing it depend upon the slowest turning ship, inclusive of the time she takes to put her helm over. I found this very markedly lately when the Warrior happened to be one of a squadron under my command; our movements were regulated by hers. She is 400 feet long, and had only manual labor to move her helm. With regard to the remarks which fell from Mr. Scott Russell, I would observe that one thing has always struck me as most important, that is, the difference of pressure on the bow and stern of a moving ship; not that caused by the raising of the wave, but the pressure against the bow caused by the motion of the vessel according to the speed at which she is going, accounts for her turning on a certain point far before the center of gravity. I believe that is a most important fact to be recognized in discussing the movements of a ship when she is turning. Mr. White has said that he has put on one side all question of wind and sea; but this question of the difference of pressure on bow and stern and of the point being so far forward on which she turns, affects us very considerably when there is any wind. When you are going ahead you do not feel it, because a slight touch of your helm moves the after part of your ship and counteracts the effect of the wind; but the very slightest wind on your beam will bring you up head to wind; and, when you are going astern, the very slightest wind on either side will bring you up stern to the wind, and your helm then is of little use. When Mr. White says it is very easy to give information about the steering power of a twin screw I think he says that the only points necessary to know are the revolutions of screw, the speed of ship, and the angle of helm required to keep the vessel straight; but the direction and force of the wind is another most important point.

One other point about "heeling" when turning. In trying ships on the measured mile, I soon observed the heeling of the ship as she turned at full speed. I at once discarded the idea of the pressure on the rudder being the cause of it, and felt assured it was what is called the centrifugal action, more properly the momentum of the upper works, and I observed that it was much more in masted ships than in unmasted ships. In the case of the French ships that were compared, they heeled over two degrees. The English ship was the Thunderer, without masts, and if the French ship had masts that would in a manner account for the difference.

Admiral **Fishbourne**. She was masted and of great draught.

The **Chairman**. That to my mind would account for it. I do not think I should quite recognize the fact that it is only due to the metacentric height. To my mind it is due to the moment of inertia of the weights above water, or as the square of the height of the center of gravity of the weights above water. I cannot help thinking it is more than simply as the metacentric height. I believe if you were to bring down all your spars from aloft and put them on deck it would not appreciably alter your metacentric height. I am only putting this as a practical idea of what I have observed when ships have been turned. I cannot speak too highly of the value of this paper. It is a subject in which we are all interested to a great degree, and we shall be very glad to hear Mr. White answer the questions which have been addressed to him.

Mr. **White**. First of all, I must express my deep obligations for the kind way in which this paper has been received. I could not help feeling in preparing it that I was coming here before a number of gentlemen who had many opportunities of making experiments such as I can never hope to have. I know something about the management of small vessels, but the management of large steamers is a thing which I have simply looked at while other people did the work; I have therefore confined myself, so far as I could, to the statement of principles which are of general acceptance, and of facts which I believe to be well authenticated. I have spared no labor in searching for facts, and my great object has been in putting these facts before you to ask for other facts. However much diagrams of the character which Mr. Scott Russell has put on the board may help us to understand the effect of the motion of the surrounding water on a vessel (either while going ahead or while turning), I think that any one who has attempted to make observations of the wave motion during steam trials will know that it is one of the most difficult subjects we have to face. We do not know exactly what is going on in the water surrounding the ship; and I am confident that a great many of those difficulties which arise in explaining the behavior of different ships arise from differences in the relative motions of the water and the ship.

I will first take up the questions which refer to heeling. Of course in this diagram (Fig. 2) the position of the "center of lateral resistance" depends greatly upon the draught of water. If instead of being what it is—a ship-shape form—it was simply a board pushed sideways, we could determine pretty closely where the center of lateral resistance would be. But it is quite evident that in a ship-shape form, if the draught is increased, retaining similar form, you will lower the line of action of the lateral resistance; and if the center of gravity could be kept to the same vertical position there would be an increase in the arm of the couple producing heeling. I quite indorse what Admiral Fishbourne said, viz, that an increase in draught not merely affects the resistance to rotation, but also affects the heeling of the ship. Of course variations in the height of the center of gravity in the ship will also affect the heeling. Supposing it were possible to bring down all the spars from aloft—although their weights are small, their vertical transfers would be great—and there would be quite a sensible fall in the center of gravity. The effect on the heeling would be felt especially in small vessels, where the arm of the heeling couple is small, and the fall of the center of gravity may cause a decrease in that distance which may be proportionately considerable. When we come to the question of a steady heel, the inertia of the ship is a factor which goes out of consideration. It seems to me mainly a question of vertical position of the center of gravity and of the center of lateral resistance. I was delighted to hear Admiral Sir Cooper Key put on record his experience of the heeling in rigged ships, because it is a matter which probably will cause further inquiry to be made. The height of the center of gravity will not merely affect the leverage of the heeling forces, but will also affect the metacentric height, that is, the position of the center of gravity in relation to the metacentre, which will govern the statical righting moment of the ship. As to the diagram which Mr. Scott Russell drew upon the board, it will suffice to say that the peculiar curvature of keel which he adopted would involve some small difficulties in docking and other difficulties of a practical character which I need not specify. Then as to the wave drawn by Mr. Scott Russell, I myself have some acquaintance with observations of actual waves. I have, for example, been outside the Iris when she has been running at nearly 19 knots an hour, but I have never seen anything approaching Mr. Scott Russell's drawing. Although I do not pretend to say what is going on in the water, I do venture to say that Mr. Russell's drawing does not represent what is going on. It must not be forgotten also that, when the vessel is on a straight course, there are the waves on both sides. The distribution of the pressure is due to dynamical conditions in this case, and not to statical. It is incorrect to count it in as a dynamical pressure, and also a statical pressure. I will not, however, pursue this matter further. I do not say that I have taken into account all the forces in my statement as to heeling, because when I speak of lateral resistance I speak of a thing which I really know little about, and I think that nobody knows much about it. We know that there must be some force on the outer side of the ship which balances the forces on the inner side. When we get a correct measure of the moment which has to be overcome before the ship heels, then, whether we take into account all the forces or not, we get a fairly correct representation of the heeling couple; that is all I have endeavored to explain as regards the heeling.

As regards the pivoting point (P, Fig. 1), I fully indorse what has been said by various speakers. From the point of view of the officer who has to direct the ship, P is the pivot point, and that is the all-important thing to him. He does not care very much where the center of the circle may be. He wants to know where the head of his ship is going. But in a mathematical sense I hope I have made it clear that the center of the circle is the center of motion. As a basis for framing complete equations of motion I do not think that Captain Colomb's diagram would be accurate. The principle of the "conservation of motions of translation and rotation" enables the equation for rotation to be framed as if the center of gravity were fixed, provided only that the whole of the forces are taken into account. I do not think we are safe to assume that we know the line of action of the lateral resistance. I hope before long, however, that we may have the opportunity of trying, in one of the torpedo boats, an experiment to determine what that vessel will do with a drop bow-rudder, and with the helm kept to midships, as Captain Colomb suggest; so that I will not venture an opinion. There were other matters in Captain Colomb's remarks to which I should have been glad to have referred, but I am afraid I have not the time to do it.

The differences in the revolutions of the screws in twin ships when turning is a matter which is not so far developed in the Thunderer trials as in many other trials. But while I quite agree in principle with what Captain Colomb has said, I must say that differences of revolutions do not necessarily imply corresponding differences in thrust, because the screws are working in water which is much affected by the motion of the ship. Unless we had dynamometrical experiments on the ends of the screw-shafts, I am sure we could not accurately estimate these differences of thrust. Repeated allusions have been made to the need for further experiments. I should be delighted to see such experiments, and may again refer to statements made in the paper. Each new ship of the navy, and many old ships, have on board "Captain's ship books," which give such information as is considered valuable to the officer in command. Amongst other things are recorded the "Constructor's steering trials," and the results of measured mile trials, with all such information about the machinery as may be given in tabular form. There is also a printed form, directing that further steering experiments of various kinds shall be made. The question of expense is one with which I have no concern; but I can assure you that in these printed forms there are detailed headings, with most distinct instructions that, for every new ship during the first year or two of her commission, steering trials shall be made. There are spaces and columns in which to record the whole of the particulars of the trials; so that when a new captain comes to the ship he ought to have in his hands the whole of those particulars, which will save him the labor of making corresponding experiments. Sir Cooper Key has alluded to the Warrior. I know that she was not the only ship in his fleet which gave him some anxiety about her steering; but I am happy to be able to say, nearly a year ago, a steam steering engine was ordered for the Warrior, and it is only waiting the opportunity to be put on board.

Captain Long spoke of the steering of the Thunderer, and the turning *outwards* of the screws. That turning outwards was adopted after careful trial. It was found that there was a sensible gain in speed, and it was adopted for that reason; but I am bound to say, so far as the steerage goes, it seems to me that is the proper way to put the screws; because the streams delivered from the lower blades then have the greater chance of reaching the rudder. While I have the greatest respect for the experience of the staff commander of the Thunderer, I believe I am right in saying that, in all the extensive steering trials, the vessel was perfectly under command at all the speeds at which she was tried. And I know, as to both the Thunderer and Devastation, I have always heard them spoken of as most manageable and well-behaved ships. As to the effect upon the steerage, produced by filling compartments forward, it is obvious that there must be considerable difficulty in saying beforehand what would happen. This is certain, that a vessel in such a condition must be much less under control; and that it would arise not merely from the change of trim, but from the fact that the masses of water, which are locked up in the vessel forward would very much affect her inertia. Besides that, the rudder would be somewhat put out of action by being less immersed, and there would be many other disturbing conditions. I can tell you, however, what has happened in many vessels which have got very much out of trim. Some time ago several vessels were built with the idea of having enormous foreholds for cargo. The machinery was pushed very far aft, and all the coal was carried aft, so that by the time the ships reached their port they were about 6 feet by the head, instead of being on an even keel; I am told that these ships did not steer well, and that they got up to their port with very great difficulty indeed, and their type has not been multiplied. As to the trial of the Hankow, and her slow turning, Captain Long is aware that in that ship there was only manual power; I believe they took one minute and three-quarters to put the helm over. There is another thing worth noting about the steamer. Having only manual power at the helm, the temptation is to make the rudder area small, and it is ridiculous, as compared with our practice in the navy, to see the rudders that are put upon many merchant steamships, including some vessels which have steering engines where there is no reason for using small rudders. I cannot help thinking that mercantile ship-builders might with great advantage look to it whether they could not increase the rudder areas in their ships, now that we have mechanical steering. Judging by the Hecla, we find that the rudder area in merchant ships might with advantage be increased if there is steam steering. With regard to Capt. J. Colomb's question as to the effect of draft upon the turning qualities of a ship, I would remark that if you increase the draft you must increase the resistance to rotation and conversely. To facilitate the maneuvering of racing yachts, great differences of draft are often adopted at the bow and stern. The well-known Jullnar is a remarkable case; her draft aft is about 16 feet and forward only a few inches.

Capt. J. C. **Colomb.** I meant to ask whether the variation of draft, caused by the probable exigencies in the service, is an element that would materially affect the turning powers of these ships, because in small vessels I know for a fact that it does.

Mr. **White.** It is so in merchant vessels, where there are great variations in draft. When merchant steamers are being transported light, they are often under little control. There are several causes for that. Of course the decrease in draft would lead to a decrease in resistance to rotation, but that carries with it usually the partial emersion of the screw, and also of the rudder-area, and there is a greater readiness to heel. All those things influence manœuvering. A ship is, no doubt, under most perfect control when she is in her load condition. Lastly, I am not aware that we have made any experiments in England with the patent log to determine its accuracy for use on steering trials. I think it is likely that such experiments may be made; but the French have made experiments, and they report against the patent log. Lieutenant Coumes has published some results.

The **Chairman.** I am sure I may have your permission to return our most cordial thanks to Mr. White.

APPENDIX A.

Turning experiments with the steamship Hankow, copied from the report of the British Association Committee for Inquiry into the steering of steamships, **1877.**

The Hankow is a single screw steamship, of 3,594.12 gross tonnage; net, 2,331.75 tons. Length, 389 feet; breadth, 42 feet 1 inch; depth, 28 feet 8 inches.

Her propeller is four-bladed, right-handed, with a diameter of 20 feet, and a pitch from 24 to 26 feet. The mean angle of its surface with a vertical athwartship plane would be 21°, hence the streams would be delivered on an average at an angle of 21° from the vertical fore and aft plane.

Experiments were conducted on March 8, 1877, in lat. 8° 50′ S., long. 153° 58′ E., between 9.20 and 11.30 a. m., as follows:

Sea smooth, or between 1 and 2 of Beaufort scale; ship drawing probably 24 feet 8 inches forward and 23 feet 8 inches aft.

FIRST EXPERIMENT.

Ship going ahead full speed (say 10 knots), engines were suddenly reversed, helm put hard aport; immediately the engines started, time noted, and bearing of ship's head by standard Admiralty compass noted, and the bearing of the ship's head also noted at every 15 seconds, until the ship came to a dead stop.

Time.			Interval.		Ship's head by compass.	Head turned to—	
						Port.	Starboard.
h.	*min.*	*secs.*	*m.*	*secs.*			
9	20	7			N. 62 W.		
9	20	22	0	15	N. 62½ W.	0½	
9	20	37	0	15	N. 66 W.	3½	
9	20	52	0	15	N 69 W.	3	
9	21	7	0	15	N. 73½ W.	4½	
9	21	22	0	15	N. 77 W.	3½	
9	21	37	0	15	N. 80 W.	3½	
9	21	52	0	15	N. 84½ W.	4	
9	22	7	0	15	N. 88 W.	3½	
9	22	22	0	15	N. 88 W.	Stationary.	
9	22	37	0	15	N. 87 W.		1
9	22	52	0	15	N. 85½ W.		1½
9	28	7	0	15	N. 84 W.		1½
9	23	22	0	15	N. 82½ W.		1½
9	23	37	0	15	N. 79½ W.		3
0	3	30	3	30		26	8½

Ship came to a dead stop in 3 m. 30 secs., and turned to port 26° in 2 m., and then to starboard 8½° for 1½ m.

SECOND EXPERIMENT.

Ship going ahead full speed, say 10 knots. Engines suddenly reversed to full speed astern; helm put hard astarboard, bearing on ship's head taken, and time as before.

Time.			Interval.		Ship's head by compass.	Head turned to—	
						Port.	Starboard.
h.	*min.*	*secs.*	*m.*	*secs.*			
9	45	30			N. 3 W.		
9	45	45	0	15	N. 91 W.	2	
9	46	0	0	15	N. 41 W.	Stationary.	
9	46	15	0	15	N. 49½ W.		1½
9	46	30	0	15	N. 37½ W.		2
9	46	45	0	15	N. 32½ W.		5
9	47	0	0	15	N. 38 W.		4½
9	47	15	0	15	N. 24½ W.		3½
9	47	30	0	15	N. 21½ W.		3
9	47	45	0	15	N. 28 W.		3½
9	48	0	0	15	N. 13 W.		5
9	48	15	0	15	N. 19 W.		4
9	48	30	0	15	N. 5 W.		4
9	48	45	0	15	N. 2½ W.		2½
9	48	53	0	8	N. 2 W.		0½
0	3	23	3	23		2	39

Ship came to a dead stop in 3 m. 23 secs. Her head payed off to port 2° during the first 15 secs., and afterwards turned to starboard 39° before coming to rest.

THIRD EXPERIMENT.

Ship going full speed ahead, say 10 knots, the engines suddenly reversed to full speed astern the helm put amidships, the bearing of ship's head noted by azimuth compass as before. Sea, wind, and weather as before.

Time.			Interval.		Ship's head by	Head turned to—	
						Port.	Starboard.
h.	*min.*	*secs.*	*m.*	*secs.*			
10	34	16	....		N. 29½ E.	....	....
			0	15	N. 29 E.	0½	....
			0	15	N. 29½ E.	....	0½
			0	15	N. 30½ E.	....	1
			0	15	N. 32 E.	....	1½
			0	15	N. 36 E.	....	4
			0	15	N. 39 E.	....	3
			0	15	N. 44 E,	....	5
			0	15	N. 46½ E.	....	2½
			0	15	N. 48 E.	....	1½
			0	15	N. 50½ E.	....	2½
			0	15	N- 51½ E.	....	1
			0	15	N. 52 E.	....	0½
			0	15	N. 53½ E.	....	1½
			0	15	N. 54 E.	....	0½
			0	15	N. 54½ E.	....	0½
			0	15	N. 55 E.	....	0½
10	38	31	0	15	N. 56 E.	....	1
0	4	15	4	15	....	0½	27

Ship came to absolute rest in 4 m. 15 secs.; her head turned to port 0½°, and then 27° to starboard, before coming to rest.

FOURTH EXPERIMENT.

In this case ship was going full speed astern, say about 9 knots, when the engines were suddenly reversed to full speed ahead; helm put hard to port; time and azimuth of ship's head noted as before. Sea, wind, and weather as before.

Time.			Interval.		Ship's head by compass.	Head turned to—	
						Port.	Starboard.
h.	*min.*	*secs.*	*m.*	*secs.*			
11	3	11	....		S. 65½ E.	....	....
			0	15	S. 66 E.	0½	....
			0	15	S. 67 E.	1	....
			0	15	S. 67½ E.	0½	....
			0	15	S. 67½ E.	Stationary.	....
			0	15	S. 66½ E.	....	1
			0	15	S. 65½ E.	....	1
			0	15	S. 63½ E.	....	2
			0	15	S. 60½ E.	....	3
			0	15	S. 57½ E.	....	3
			0	15	S. 53½ E.	....	4
11	5	56	0	15	S. 48 E.	....	5½
0	2	45	2	45	....	2	19½

Ship came to dead stop in 2 m. 45 secs., and her head turned 2° to port in the first 45 secs., and 19½° to starboard in the next 2 minutes.

FIFTH EXPERIMENT.

Making the circle from rest; hard to port; full speed ahead. Wind and sea as before.

Ship started at full speed from absolute rest, with the helm hard aport, and at the instant of starting an empty flour barrel was dropped from the stern, to mark the point started from.

Time.			Interval.		Ship's head by compass.	Arc turned.
h.	*min.*	*secs.*	*m.*	*secs.*		
9	27	54	....		N. 56½ W.	....
	28	24	1	30	N. 54 W.	2½
	28	54	0	30	N. 49 W.	5
			0	30	N. 38 W.	11
			0	30	N. 28 W.	10
			0	30	N. 18 W.	10
			0	30	N. 5 W.	13
			0	30	N. 6 E.	11
			0	30	N. 19 E.	13
			0	30	N. 30 E.	11
			0	30	N. 43½ E.	13½
			0	30	N. 58 E.	14½
			0	30	N. 74 E.	16
			0	30	N. 89 E.	15
			0	30	S. 75 E.	16
			0	30	S. 61 E.	14
			0	30	S. 46½ E.	14½
			0	30	S. 33 E.	13½
			0	30	S. 20 E.	13
			0	30	S. 7½ E.	12½
			0	30	S. 4½ W.	12
			0	30	S. 16½ W.	12
			0	30	S. 30 W.	13½
			0	30	S. 45½ W.	15½
			0	30	S. 61 W.	15½
			0	30	S. 78½ W.	17½
9	40	54	0	30	N. 84 W.	17½
9	41	24	0	30	N. 67 W.	17
9	41	40	0	16	N. 57 W.	10
0	13	46	13	46	....	Mean angular velocity, 27′ per second.

Ship came outside barrel about 150 feet, when it was abreast taffrail, *i. e.*, it was on our starboard side at conclusion.

W. SYMMINGTON,
Commander Steamship Hankow.

APPENDIX B.

Description of plan for ascertaining ships' curves when turning, proposed by Captain Long.

Shortly it consists of using Mr. Martin's plan, with one additional box or buoy, and two additional angles, the object being to connect the various points on the curve with the position of center of gravity, when helm begins to move, and original course, as detailed by Mr. White.

I need only remark that if a rolling batten were placed vertically at each extremity of base with a white mark at height of observer's eye, there seems no reason why the angles should not be taken with a sextant.

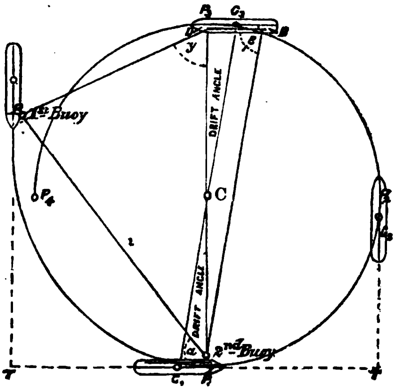
Observations required—

1. At instant of moving helm drop a buoy from inner bow abreast cross battens; note time.
2. Note time helm is hard over.
3. When ship has turned through 90°, drop a second buoy from same place, and observe the angle *a* subtended by the first buoy, and after end of base line; note time.

4. When the second buoy comes abeam by cross-battens, at fore end of base line, take angle β from after end, as in Mr. Martin's plan, and also angle γ from fore end of base line, being angle between the two buoys; note time.
5. Note time ship has completed circle.

If an accurate account of speed is required, which is most desirable, one of the methods, either Dutchman's log observations, or Sir Cooper Key's plan, as mentioned by Mr. White, must be used.

H. M. S. THUNDERER'S THIRD EXPERIMENT PLOTTED TO SHOW PROPOSED METHOD.



Scale ¼ inch = 100 feet.

PP₁, &c., positions of pivoting point of ship.
GG₁, &c., " center of gravity.
C center of circle.

CALCULATION.

In triangle P_1BD if l be the length of base line on board—

$$l \tan \beta = \text{final diameter, or } P_1P_3.$$

$$\text{In triangle } PP_1D \text{ angle at } P = 180 - \left\{ \gamma + \overline{90 - \alpha} \right\}$$

$$\text{Hence } PP_1 \text{ or chord of first quadrant} = \frac{P_1P_3 \sin \gamma}{\sin P} = \frac{l \tan \beta \sin \gamma}{\sin P}$$

Also TT, or tactical diameter, $= \frac{P_1P_3}{2} + PP_1 \cos \alpha$; and drift angle, or P_1CG_1 may be found from $\tan C = \frac{P_1G_1}{R}$, R being radius of circle.

As an example, I have taken the angle supposed to be observed off the plan, in a convenient form of record.

Time.			Interval from origin.		Observations.
h.	*min.*	*secs.*	*m.*	*secs.*	
12	32	42			Helm began to move, dropped buoy No. 1.
12	33	1	0	19	Helm hard over.
12	34	11	1	29	Ship turned 90°, dropped buoy No. 2, obsd. $< \alpha = 54°$.
12	36	40	3	58	Ship turned 270°, obsd. $< \beta = 80° 30'$ $< \gamma = 68°$.
12	38	2	5	20	Circle complete.

Any number of additional observations might be made as to times of passing through various azimuths, speed, &c.

The above may be plotted to scale or worked out thus:

$$\begin{array}{lcll}
\text{Log } l & = & 2.301030 & \\
\text{Log tan } \beta & = & .776394 & \\ \hline
\text{Log } P_1P_3 & = & 3.077424 & \text{final diameter} = 1,195 + 50 = 1,245 \text{ feet.} \\
\text{Log sin } \gamma & = & 9.967166 & \\ \hline
 & & 13.044590 & \\
\text{Log sin } P & = & 9.986904 & \\ \hline
\text{Log } PP_1 & = & 3.057686 & \text{chord of 1st quadrant} = 1,142 \text{ feet.} \\
\text{Log cos } a & = & 9.769219 & \\ \hline
\text{Log } TP_1 & = & 2.826905 & TP_1 = 671 \text{ feet.}
\end{array}$$

$$\frac{P_1P_3}{2} = 622 \text{ feet.}$$

$$\begin{array}{lr}
TT & 1,293 \text{ feet.} \\
\text{Add half breadth of ship} \ldots\ldots\ldots\ldots & 31 \text{ feet.} \\ \hline
 & 1,324 \text{ feet, tactical diameter of center of ship.}
\end{array}$$

Also tan C, or drift angle $= \frac{P_1b_1}{R} = \frac{98}{620}$

$$\begin{array}{lcl}
\text{Log } 98 & = & 1.991226 \\
\text{Log } 620 & = & 2.792392 \\ \hline
\text{Log tan } C & = & 9.198834 \quad C = 8^\circ\ 59'.
\end{array}$$

The drift angle for any point of a ship is the angle; an object must be before the beam (if abaft pivoting point) in order to turn round it without altering distance.

Space forbids entering at present into the numerous practical questions which present themselves. I would only remark that all methods share the defect of difference of drift between ship and buoy, and if anything beyond the final diameter is required, we at once get upon the question of obtaining correct azimuths which I touched on in my remarks.

As the length PG can only be determined by experiment, and is variable at different speeds and helm angles, it will be most satisfactory if G is made the center of the base line, when G_1G_3 can be easily deduced from the final diameters. The accurate length of PG is only required for the determination of drift angle, and angle β is in fact very nearly equal to the drift angle.

THE MALLORY PROPELLER.

Fig. 1.

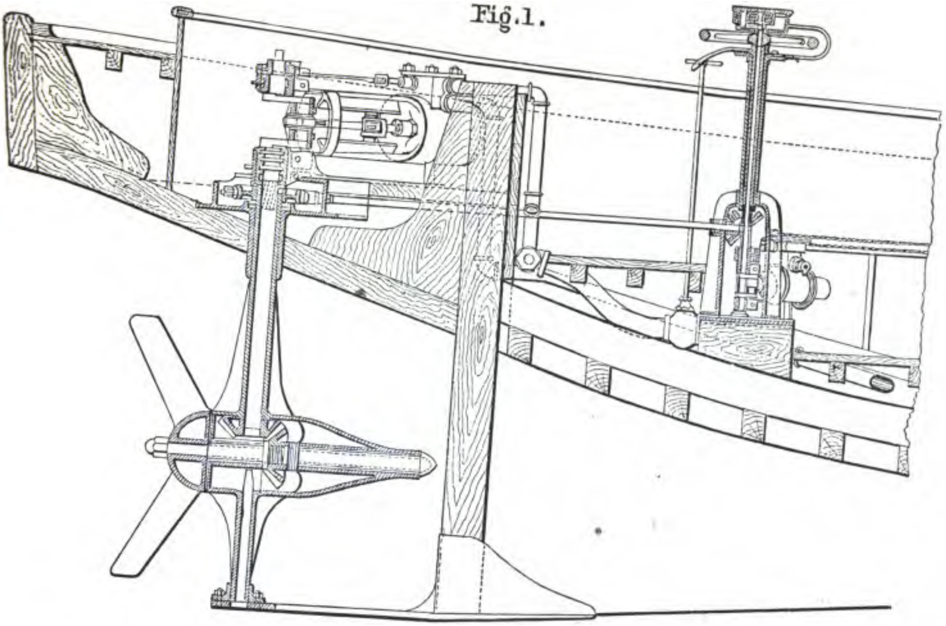


Fig. 2.

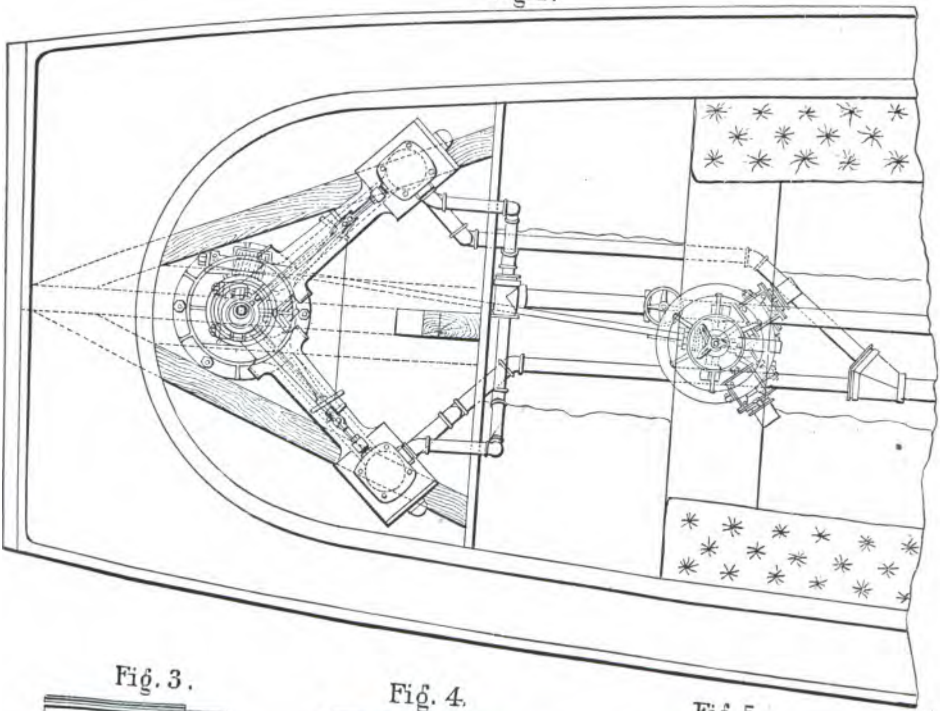


Fig. 3.

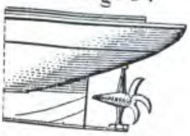


Fig. 4.

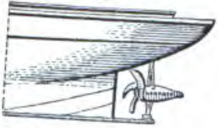


Fig. 5.

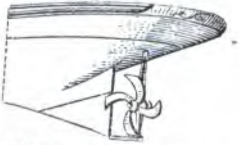


Fig. 1 is a vertical longitudinal section of the stern portion of a ship, showing the apparatus; Fig. 2 being a plan. Fig. 3 shows the position of the propeller when the vessel is going ahead, and Fig. 4 when she is moving astern; whilst Fig. 5 shows its position when the ship is being maneuvered laterally.

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Lecture on the turning powers of sh
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